THE

JOHN MURRAY EXPEDITION

1933—34

II

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THE

JOHN MURRAY EXPEDITION 1933–34

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VOLUME III

GEOLOGICAL & MINERALOGICAL INVESTIGATIONS

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[Issued March 23rd, 1940.]

PLATES AND CHARTS

BRITISH MUSEUM (NATURAL HISTORY)

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I. BASALTS FROM THE CARLSBERG RIDGE, INDIAN OCEAN

BY

JOHN D. H. WISEMAN, M.A., Ph.D.

WITH AN APPENDIX ON THE RADIUM CONTENT OF SOME SUB-OCEANIC BASALTS FROM THE FLOOR OF THE INDIAN OCEAN

BY

J. H. J. POOLE, Sc.D.

WITH ONE PLATE AND FOUR TEXT-FIGURES

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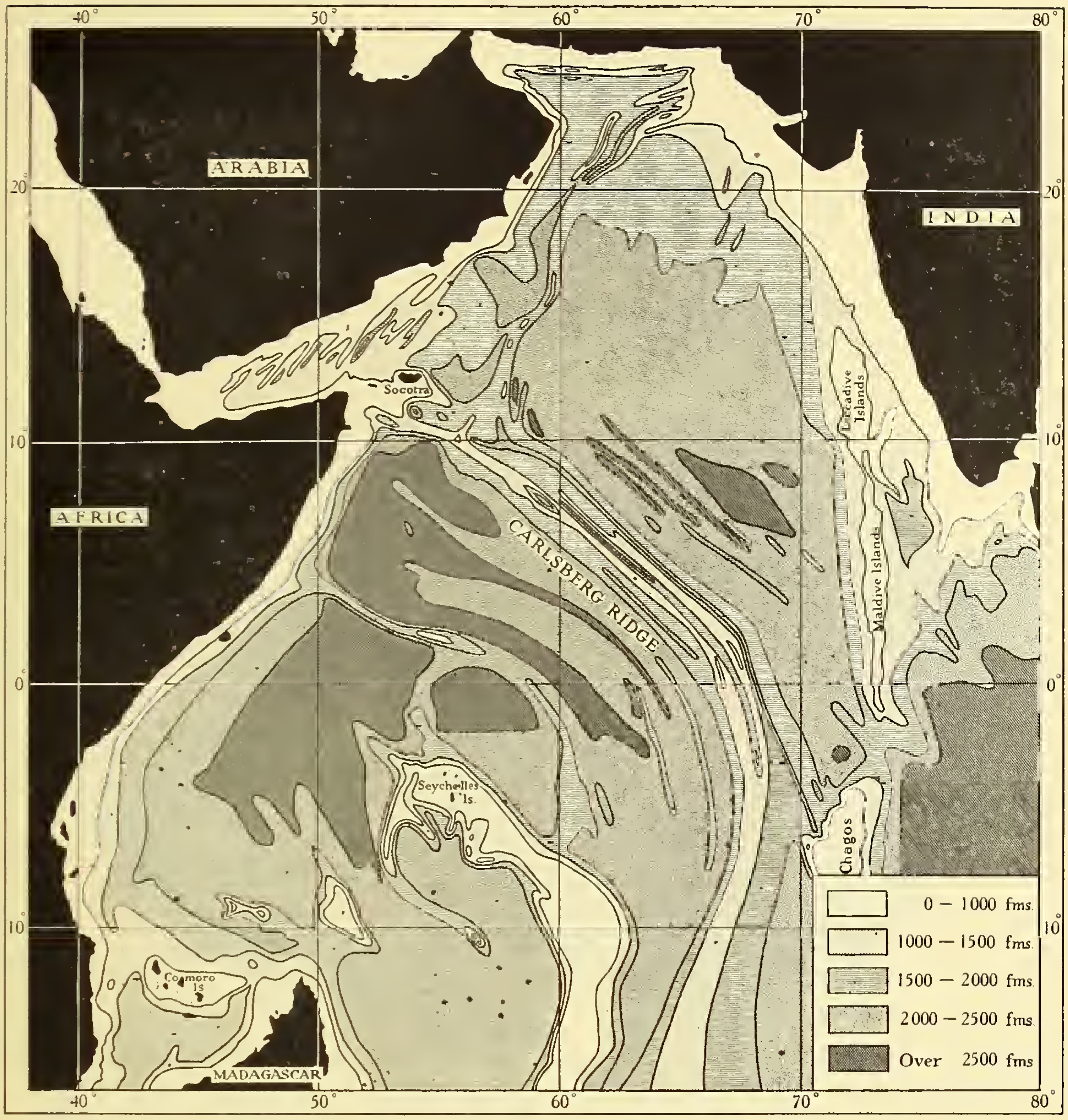
I. INTRODUCTION.

During the cruise of the "Mabahiss" from Zanzibar to Colombo at Station 133 (1° 25′ 54″ S. to 1° 19′ 42″ S. and 66° 34′ 12″ E. to 66° 35′ 18″ E.) several small rock fragments were brought up in the Monégasque net; and, since at this position there is no possibility of the material being transferred by floating ice, these specimens are of some interest as samples of oceanic rock foundations. The interest arises from our very limited knowledge of this subject, and such facts as are available are generally based on the petrography of oceanic islands or more indirectly on geophysical considerations. It was thought therefore that a description of both the chemical and petrographical features of these rocks, taken from the bottom of the ocean, would be a useful contribution, and thereby give some critical evidence concerning the theory held by many geologists that a large area of Gondwanaland now lies submerged to the west of India.

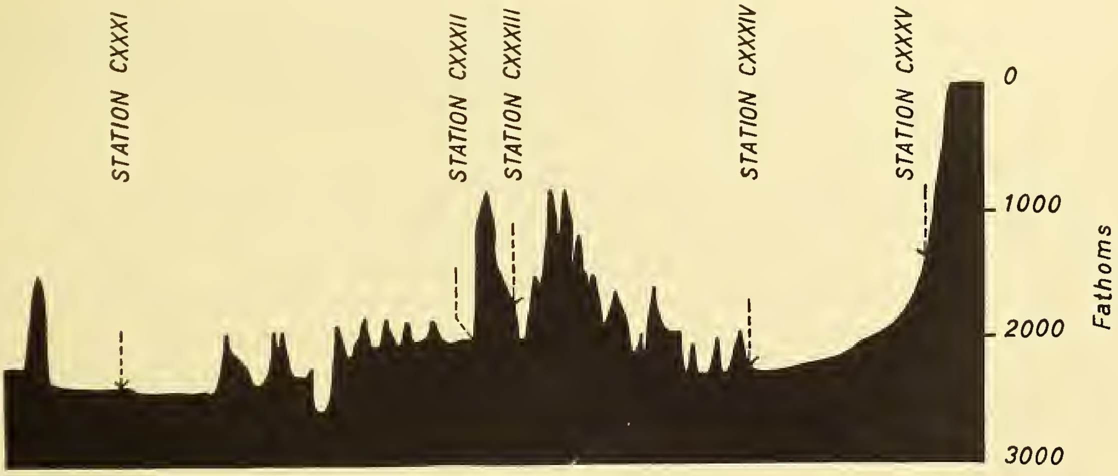
The Carlsberg Ridge, on which Station 133 is situated, was originally postulated by the Dana Expedition (Schmidt, 1932), but it was left for the John Murray Expedition to carry out a more detailed survey of this important tectonic feature. The ridge (Text-fig. 1A), according to Farquharson (1936), the Surveyor of the expedition, commences near Socotra, continues with a S.E. trend to the equator and then gradually swings round to the S.W., including in its course the Island of Rodriguez. Owing to the scarcity of soundings it is, perhaps, premature to consider it continuous, but the work of the Murray Expedition indicates that the ridge, perhaps crossed here and there by depressions, represents a major structural feature of the Indian Ocean. Inasmuch as it is a well established principle of geology that the greater crustal movements are invariably accompanied by vulcanicity, so the occurrence of igneous rocks at Station 133 is not unexpected, and it would seem that, if a further search were made along this ridge, volcanic ejectamenta would be found in some of the trawls.

The Carlsberg Ridge is a complex structure consisting of a series of ridges and furrows, which are suggestive of folding perhaps accompanied by faulting. At Station 133 the trawl was at a depth of approximately 3385 metres, and the topography of the sea floor in this neighbourhood is shown in Text-fig. 1B. It is interesting that at this station the oxygen content at first decreases, and after reaching a minimum increases towards the bottom owing to the presence of Antarctic water, whilst the temperature at 3000 metres was 1·9° C. The specimens are thus associated with sea-water at a very low temperature, containing at least 2·4 c.c. of oxygen per litre. No attempt was made to obtain a Bigelow tube sample, so the nature of the mud, if any, associated with the specimens is unknown.

About forty rock fragments, varying in size from $3\frac{1}{2}$ in. to $\frac{1}{2}$ in., came up in the trawl. Their shapes vary considerably, as shown in Pl. I, but apart from three or four more rounded specimens, there is a general tendency to angularity. All the rocks have a black appearance, but in the majority this skin is of negligible thickness. Exceptionally, however, it may attain to $\frac{1}{3}$ in. (St. 133, 8), and then the specimens are rounded, as illustrated in Pl. I, fig. 1. If such a specimen is sectioned, the interior is revealed to be rock surrounded by a peripheral black coating (Pl. I, fig. 5). The junction between the coating and the kernel is sharp, and when the exterior zone is removed the angularity of the interior rock is well exhibited (Pl. I, fig. 4). It may be asked therefore whether all the specimens had originally a peripheral coating. This may well be so as this coating is easily removed, and in addition it is difficult to suggest a process capable of producing



Text-fig. 1a.—Chart of Indian Ocean.



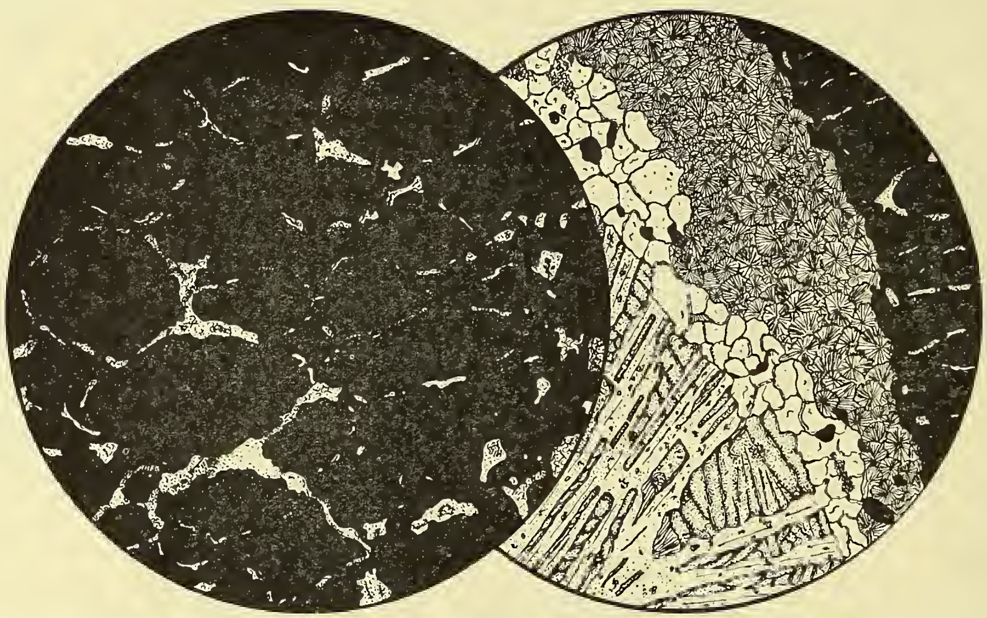
Text-fig. 1b.—Section south-west of the Kardiva Channel.

such a feature on a few fragments and not on others. But against this hypothesis it could, with some justification, be urged that with the small amount of material in the net the trituration would be negligible, and so the question must be left unsettled.

II. NATURE OF PERIPHERAL COATING.

Concerning the nature of this coating it must be indicated that, in addition to the dark material, small light fragments occur, which have a rough radial arrangement. This feature can be made out in Pl. I, fig. 5, but is more clearly exhibited in Pl. I, fig. 3, which

A B



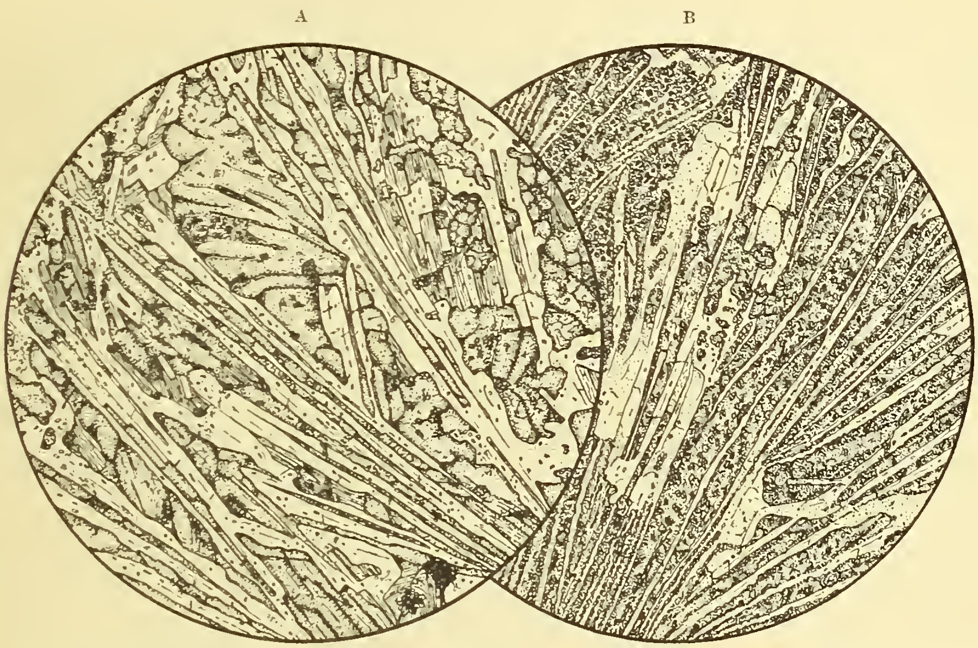
TEXT-FIG. 2.—Nature of peripheral coating, Carlsberg Ridge. A. × 33. Peripheral coating of variolitic basalt (St. 133, 8); the small light fragments have a tendency to outline globules of dark opaque manganese material. B. × 68. Junction of coating with variolitic basalt (St. 133, 8); the variolitic basalt is separated from the manganese material by quartz grains and a zone of fibrous chlorite arranged in stellate groups.

is magnified seven times. The junction between the rock and the coating is sharp, whilst the light-coloured material lies in a direction approximately perpendicular to the rock surface. A discussion concerning the nature of this coating will be given in a later report, and as it is similar to the manganese nodule material found at Station 166, only a brief description will be given.

One of the most remarkable features is the large amount of water which the peripheral coating contains, for a determination by the usual Penfield method, without any special precautions being taken to avoid volatiles, gave 28·35% total water, of which 18·75% came off below 105° C. Further, when the material is treated with dilute hydrochloric acid, abundant chlorine is liberated, and small flakes of a colourless insoluble material are left behind. The majority of the flakes have a low refractive index (*ca.* 1·480), and they are for the most part isotropic, though a few may show slight birefringence. They are of two main types: those with a wavy or perhaps shard-like appearance when examined under the high power of the microscope, whilst others have a wavy structure

in one portion and a featureless surface elsewhere. Their colour is faintly brown, but the intensity is very variable, even in a single flake. It will be sufficient for our purpose to remark that the flakes have characters similar to those occurring in the manganese nodules from Station 166. In addition to this isotropic substance, small quartz grains occur in the insoluble residue, but they are comparatively rare.

In a thin section of one of the rounded specimens (St. 133, 8), a small vein of manganese material, having its origin in the periphery, occurs in the interior rock. This vein can be seen in Pl. I, fig. 5, where it is shown by its slightly darker colour. In thin section the peripheral isotropic material has a colour of intenser brown than when isolated



TEXT-FIG. 3.—Variolitic basalts, Carlsberg Ridge. A. × 68. Augite-basalt (St. 133, 8); the felspar occurs as thin untwinned laths, and in places the augite is altered to chlorite (linear shading). B. × 152. Oxidized basalt (St. 133, 5); the variolitic character of this basalt can still be made out in spite of its alteration; most of the original glass is oxidized and the brownish alteration product is shown by lighter shading.

by means of dilute hydrochloric acid, though it is occasionally colourless. This feature may be connected with a film of manganese masking some of the flakes. Under the microscope the flakes have a tendency in places to outline globules of dark opaque material (Text-fig. 2A).

Occasionally the black opaque material occurs in direct contact with the interior basalt without any trace of a transition, but generally a thin zone of quartz grains, giving undulose extinction, is found between it and the interior, whilst in other places the quartz grains are separated from the manganese material by a green fibrous mineral, arranged in small stellate groups (Text-fig. 2B). This mineral, giving first-order interference colours, has positive elongation, and is probably a chlorite. In a tangential section of the periphery, in addition to the isotropic substance and occasional quartz grains, small felspar crystals, showing lamellar twinning, and more rarely diopside can be recognized.

III. PETROGRAPHY OF ROCKS.

About fifteen thin sections were cut from the Carlsberg Ridge specimens, so a representative idea can be formed about the composition of the rocks from this station. Considered as a whole, they are of a decided basaltic character, but no olivine has been found. Many of the rocks have undergone considerable chloritic alteration, but others are moderately fresh. Four representative moderately fresh rocks have been analysed, and the petrography and chemistry of these types will be described below.

(*a*) Augite-Basalt.

The interior of specimen Station 133, 8, of which the peripheral coating has been previously described, is a very fine-grained holocrystalline basalt (Text-fig. 3A). The felspar, occurring as thin untwinned laths, generally shows a sub-ophitic relation to the augite, but in addition tiny granules of augite sometimes occur inside it. In composition it is an oligoclase with about 25% anorthite ($\gamma = 1{\cdot}548 \pm 0{\cdot}003$). The augite, having a faint purple colour suggestive of titanium, occurs for the most part as small crystals between the felspar laths and exhibits no crystal shape. It is optically positive, and the refractive indices are: $\gamma = 1{\cdot}732 \pm 0{\cdot}004$, $\alpha = 1{\cdot}703 \pm 0{\cdot}004$. In clinopinacoidal sections the maximum extinction angle is 50° (Z : *c*). A green fibrous chlorite, showing low interference colours and with positive elongation, is associated in small amounts with the augite, and is clearly, for the most part, secondary after the augite. No olivine occurs in the thin section, agreeing with its absence in the norm, and quartz has not been detected.

The chemical composition of this basalt is given in column 1, Table I. In preparing the rock for analysis care was taken to avoid both the manganese vein and the peripheral portions. The main chemical feature of the basalt is the high soda and low potash, and in connection with the manganese periphery it should be noted that the basalt contains a normal amount of MnO. The normative composition of the felspar is $Ab_{61}An_{39}$, whilst the observed composition is $Ab_{75}An_{25}$. An altered augite-andesite described by Thomson (1909) from Mt. Anketel, Western Australia, has a similar composition (column 2), except that the titania and soda are lower, whilst the manganese is unusually high. A basalt from Folsam, New Mexico (Washington, 1917*a*) (column 3), is chemically similar, apart from the slightly lower soda and the appreciably higher potash. The basalt erupted by Stromboli (Perret, 1916) in November, 1915, has a similar composition (column 4), but the soda is lower and the potash very much higher. A close comparison may be made with a post-Eocene basaltic dolerite described by Chautard (1907) from Cape Verde, Senegal (column 5), but the potash content is more than three times as much as in the Carlsberg Ridge specimen.

These comparisons illustrate the unusual composition of the Indian Ocean basalt, for rocks of similar composition usually contain more potash, and apart from the abnormal, very much altered augite-andesite from Mt. Anketel the author is not aware of any rock showing similar chemical characteristics. The main fact to be explained is the high soda and the low potash, and it will be subsequently shown that this feature characterizes all the basalts from the Carlsberg Ridge. The possibility of this being related to the action of sea-water is discussed on a later page.

TABLE I.

	(1)	(2)	(3)	(4)	(5)
SiO_2	52·24	53·11	53·27	51·05	52·15
TiO_2	1·83	0·40	1·30	0·83	2·31
Al_2O_3	15·02	15·55	15·43	15·09	15·40
Fe_2O_3	2·93	1·26	2·43	2·07	2·60
FeO	6·31	7·17	6·50	6·88	7·45
MnO	0·14	0·59	0·12	0·13	—
MgO	6·01	6·50	6·16	6·52	7·05
CaO	8·73	8·93	8·18	11·34	8·31
Na_2O	4·02	3·03	3·51	2·53	3·85
K_2O	0·21	0·28	1·71	2·02	0·70
H_2O+	2·25	3·12	0·62	0·15	0·88
H_2O-	0·50	0·04	—	—	—
P_2O_5	0·20	—	0·50	1·44	0·09
CO_2	*Nil*	0·32	*Nil*	—	—
Inclusive	—	0·07	—	—	—
	100·39	100·37	99·73	100·12	99·70
Norms.					
Quartz	2·34	3·66	1·14	—	—
Orthoclase	1·11	1·67	10·01	12·23	4·45
Albite	34·06	25·15	29·34	22·53	32·49
Anothite	22·24	28·08	21·41	27·24	22·24
Diopside	16·13	13·20	12·61	13·82	15·27
Hypersthene	13·56	22·37	17·34	12·38	14·82
Olivine	—	—	—	4·22	2·50
Magnetite	4·18	1·86	3·48	2·09	3·71
Apatite	0·34	—	2·43	1·52	—
Ilmenite	3·50	0·76	1·34	3·70	4·10

(1) Basalt with augite and oligoclase (St. 133, 8), Indian Ocean. Analyst: J. D. H. Wiseman.

(2) Augite-andesite, Mt. Anketel, Western Australia. 'W. Austr. Geol. Sur. Bull.,' XXXIII, 1909, p. 148.

(3) Basalt, Folsom, Colfax County, New Mexico. 'U.S. Geol. Sur.,' Prof. P. XCIX, 1917, p. 608.

(4) Basalt. 'Amer. Journ. Sci.,' XLII, 1916, p. 451.

(5) Basaltic dolerite, Pointe de Fanu, Cape Verde, Senegal. 'Bull. Soc. Geol. Fr.,' VII, 1907, p. 437.

(*b*) OXIDIZED VARIOLITIC BASALT AND DISCUSSION ON SUBAQUEOUS OXIDATION OF GLASSY BASALTS.

The second specimen analysed (St. 133, 5) is a fine-grained rock with ovoid areas of about 1 mm. diameter, filled with a soft brownish substance. In thin section it is variolitic (Text-fig. 3B), the minute felspar laths being arranged in a radiating fashion. A felspar phenocryst occurs in one portion of the slide, and its composition is oligoclase. Tiny granules, frequently very much altered, occur between the felspar laths, and

occasionally they are well enough preserved to be identified as augite, but more generally these granules are too much altered for optical determinations. In addition to the above minerals a brownish substance, which may either be isotropic or anisotropic, occurs both in the ground-mass as well as in the ovoid areas. The refractive index of this material ranges from about 1·570 to 1·585. Peacock and Fuller (1928) have described a basaltic glass from Columbia River, Washington, with a refractive index of 1·583, and so it seems probable that some of the isotropic material may represent unaltered volcanic glass. The brownish substance is in places fibrous and slightly birefringent, and it is suggested that the fibrous material is an alteration product of the glass. The common alteration of basic volcanic glass is to palagonite—a term applied by von Waltershausen (1845) to material forming the brown ground-mass of a tuff from Palagonia, Sicily. Later von Waltershausen (1853) realized the structural relation of palagonite to basic volcanic glass, whilst the transition of glass to palagonite has been emphasized more recently by Fermor (1925) and Peacock (1928). In a recent paper the latter author (Peacock, 1926) indicates that the Icelandic palagonite-tuffs have originated by the hydration of a basic volcanic glass, and he emphasizes that hydration is accompanied by extensive oxidation of the iron content—an opinion which to-day finds very general acceptance. All investigators of the palagonite problem appear to agree on its low but variable refractive index, and frequent statements occur in the literature that palagonite is sometimes birefringent, due to incipient molecular organization in the gel structure. Murray and Reynard (1891*a*) in their descriptions of similar material dredged by the " Challenger " mention the transition of basic glass into palagonite ; and these authors record the anisotropy sometimes exhibited, but no accurate refractive index measurements are given. In view of the observations of these investigators it might be urged that the brownish anisotropic material in the specimen under consideration was produced by hydration and is to be identified as palagonite. With this identification, however, I cannot concur, since the refractive index is much too high. It is at present impossible to arrive at a positive conclusion about its exact nature, but it is interesting to mention that this material has also been found at Station 166, where it is associated with palagonitic material of low refractive index. It is possible to suggest as an hypothesis that the fibrous substance represents a chlorite with a large amount of water between the thin fibres, but such a suggestion must be taken with reserve. It is, however, safe to assume from the analytical evidence that the anisotropic substance is produced during hydration, since there is 2·46% of uncombined water in the analysis, but no hypothesis, other than suggesting that the fibrous material is a chlorite, can be advanced to explain its moderately high refractive index.

The results of the chemical investigation on this rock are given in column 1, Table III, and chemically it is similar to the augite-basalt (Table I, column 1) previously described. As before, the rock is characterized by negligible potash and over 3% soda. The silica is slightly lower than before, but the alumina is almost identical. Concerning the state of oxidation of the iron it is interesting to note that the iron is mostly in the ferric condition, and this oxidation is correlated with the hydration of the rock. In this connection the author (Wiseman, 1936*a*) has recently described a rock, dredged from a depth of 744 fathoms near to Providence Reef, showing a similar oxidation. In this paper it is concluded that the oxidation is directly connected with the sea-water, and is not due to subaerial weathering, as proposed by Pirrson (1914*a*) for the basalts of Bermuda

Island. It is difficult to imagine in the case of the Carlsberg Ridge variolitic basalt, found at a depth of nearly 4000 metres, how subaerial oxidation can have occurred, unless of course we regard it as representing a sunken remnant of Gondwanaland—a hypothesis which will subsequently be shown to be highly improbable. In the literature confirmatory evidence for the oxidizing power of sea-water is found in a recent paper by Correns (1930*a*), who examined a basalt collected by the Meteor Expedition from the Mid-Atlantic Ridge. Correns gives analyses of both the kernel and peripheral portions ; in the interior he reports 2·30% Fe_2O_3 and 7·55% FeO, whereas in the periphery the amounts are 16·56% Fe_2O_3 and 0·93% FeO. These figures give a very positive demonstration of the oxidation and the concentration of the total iron in the periphery. Similarly, in analyses by Sipöcz (Murray, J., and Reynard, 1891*b*) of the peripheral and interior portions of a basalt dredged from near the Sandwich Islands, oxidation occurs, and we may judge from these and other examples that the protective action of sea-water, as suggested by Pirrson and others, is unsupported by oceanographical investigations. Such a feature is, of course, not really surprising, for according to modern investigation, sea-water, even at great depths, frequently contains appreciable oxygen. Thus, at Station 133 the oxygen content at a depth of 3000 metres is 2·41 c.c. per litre, whilst at the surface it contains 3·68 c.c. per litre. It is this latent oxygen which is responsible for the subaqueous oxidation in many oceanic basalts, but the Murray specimens indicate that the presence of oxygen is not sufficient unless the rock is of a suitable character.

In the ankaratrite-limburgite from Providence Reef the augite and olivine is set in a dark opaque substance, which represents original glass, whilst the basalt described by Correns from the Mid-Atlantic Ridge also contains glass in its interior. Similarly, in the specimen dredged by the "Challenger" Expedition from near the Sandwich Islands the interior is glassy whilst the exterior is largely palagonite. From these examples we may suggest that the presence of glass favours subaqueous oxidation, and in this connection it is significant that glass-free basalts from the Carlsberg Ridge have suffered no such change. The available analytical information, bearing on the problem of oxidation and the nature of the rock, is summarized, for convenience, in Table II.

TABLE II.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)
Fe_2O_3 . .	16·56	7·62	6·74	5·89	2·93	2·30	2·21	1·91	1·73	14·57
FeO . .	0·93	2·28	4·42	4·70	6·31	7·55	7·39	6·68	10·92	—
H_2O- . .	6·26	6·61	2·46	1·03	0·50	0·27	0·86	0·25	n.d.	n.d.

(1) Olivine-basalt, peripheral portion, Mid-Atlantic Ridge. 'Chemie der Erde,' V, 1930, p. 83.
(2) Ankaratrite-limburgite. Originally glassy. Providence Reef. 'Trans. Linn. Soc. Zool.,' ser. 2, XIX, p. 440.
(3) Variolitic basalt (St. 133, 5), Carlsberg Ridge. Contains some glass.
(4) Variolitic basalt (St. 166, 6° 55′ N., 67° 11′ E.). Originally had a glassy base.
(5) Basalt (St. 133, 8), Carlsberg Ridge.
(6) Interior of glassy basalt, Mid-Atlantic Ridge, *op. cit. supra.*
(7) Basalt (St. 133, 12), Carlsberg Ridge.
(8) Dolerite (St. 133, 15), Carlsberg Ridge.
(9) Unaltered glass nucleus, near Sandwich Isles. 'H.M.S. "Challenger", Deep Sea Deposits', 1891, p. 463.
(10) Decomposed coating of basic volcanic glass, near Sandwich Isles, *op. cit. supra.*

An examination of this table reveals that a high percentage of ferric iron is invariably accompanied by a large amount of uncombined water, a feature which is very well illustrated by comparing the 2·46% of H_2O- (column 3) in the oxidized variolitic basalt with the low uncombined water content in the unoxidized rocks (columns 5, 7, 8) from the same station. An oxidized variolitic basalt, originally glassy, from Station 166 shows the same high water content (column 4), whilst a similar feature is shown by the Providence specimen (column 2). In the basalt from the Mid-Atlantic Ridge nearly 6% more water occurs in the oxidized periphery than in the glassy interior (columns 1 and 6). The " Challenger " specimens (columns 9 and 10) show a great increase of ferric oxide in the peripheral zone as compared with the unaltered interior, but unfortunately the analyses by Sipöcz are decidedly incomplete, for H_2O- is not determined, nor is there any estimation of ferrous oxide in the decomposed coating.

After what has been stated above there can be little doubt that the presence of glass was essential, in the specimens under consideration, for subaqueous oxidation of basalts. It has been previously mentioned that this contention is supported by the four Carlsberg Ridge analyses, for three rocks containing no glass are unaffected by sea-water (columns 5, 7 and 8). It is impossible, in this case, to account for this by a difference in conditions, for all the specimens are from the same locality ; so the conclusion that the subaqueous oxidation is, in general, governed by the glassy character of the rock, seems justified. It is not suggested by this that all glassy rocks must *a fortiori* have undergone oxidation, for they may be of too recent age, or on the other hand, the surrounding conditions may not be suitable for such a process to take place.

A fairly close comparison, apart from the state of oxidation of the iron, can be made with a basalt analysed by Washington (1917*b*) from Mt. Etna (Table III, column 2), and with a basalt from Victoria, Australia (Table III, column 3). In both these basalts the ferrous iron content approximates probably to that occurring in the variolitic basalt before oxidation, whilst in addition the amount of uncombined water is low. A significant feature is the appreciable potash as compared with the insignificant amount in the Carlsberg Ridge specimen. In a basalt from Lake Balaton, Hungary (Emszt, 1906) (Table III, column 4) the percentage of ferric oxide is greater than ferrous, and the soda is approximately the same as in the Carlsberg Ridge specimen, whilst the potash is moderately low. Unfortunately Emszt gives no petrological description of this rock, nor has the uncombined water been estimated, so it is impossible, from the original paper, to determine its true nature. In column 5 of the same table the composition of a basalt showing similar chemical features is recorded from Bradshaw Mountains, Arizona (Jagger and Palache, 1905), and it is described as representing a border facies approximating to the surrounding basalts in composition, but probably representing a locally differentiated facies of basalt. Washington classes the analysis in his tables under the heading of " altered rocks ", a classification which seems justifiable on account of the 1·24% of uncombined water.

From this brief comparison it may be concluded that, although fresh basalts of similar composition—apart from the state of oxidation of the iron—occur in other areas, they invariably contain higher potash. The lowness of potash is, as will be emphasized later, a feature characteristic of the Carlsberg Ridge station.

TABLE III.

	(1)	(2)	(3)	(4)	(5)
SiO_2	47·58	48·46	47·46	46·78	46·74
TiO_2	2·10	2·03	3·10	1·78	1·04
Al_2O_3	15·05	15·92	16·12	14·66	16·96
Fe_2O_3	6·74	3·42	2·96	7·25	6·44
FeO	4·42	8·00	9·39	5·22	4·13
MnO	0·14	0·18	0·25	—	0·23
MgO	5·71	5·05	5·70	6·81	6·18
CaO	10·97	10·02	7·27	9·61	11·90
Na_2O	3·19	4·13	3·51	3·08	3·13
K_2O	0·04	1·61	1·74	0·45	0·50
H_2O+	0·99	0·01	0·57	1·78	0·89
H_2O-	2·46	0·03	0·72		1·24
P_2O_5	0·23	0·65	0·78	0·45	0·56
CO_2	*Nil*	*Nil*	*Nil*	—	0·58
Inclusive	—	0·23	0·07	—	—
	99·62	99·74	99·64	99·37	100·52
Norms.					
Quartz	2·64	—	—	—	—
Orthoclase	0·56	9·45	10·56	2·78	2·78
Albite	27·25	15·68	29·34	28·82	26·20
Anorthite	26·41	20·29	23·07	24·74	31·14
Nepheline	—	4·83	—	—	—
Diopside	21·17	20·24	6·12	15·61	19·65
Hypersthene	4·50	—	5·44	8·61	1·56
Olivine	—	8·50	11·71	1·12	4·11
Magnetite	8·82	4·87	4·41	10·67	9·28
Hæmatite	0·64	—	—	—	—
Apatite	0·34	1·68	2·02	1·01	0·93
Ilmenite	3·95	3·80	5·93	3·34	1·82

(1) Variolitic basalt (St. 133, 5), Carlsberg Ridge, Indian Ocean. Analyst: J. D. H. Wiseman.

(2) Basalt, lava of 1910, Mt. Etna, Sicily. 'U.S. Geol. Sur.,' Prof. P. XCIX, 1917, p. 618.

(3) Basalt, Newlyn, Victoria. 'A. R. Sec. Min. Vict.,' 1912, p. 62.

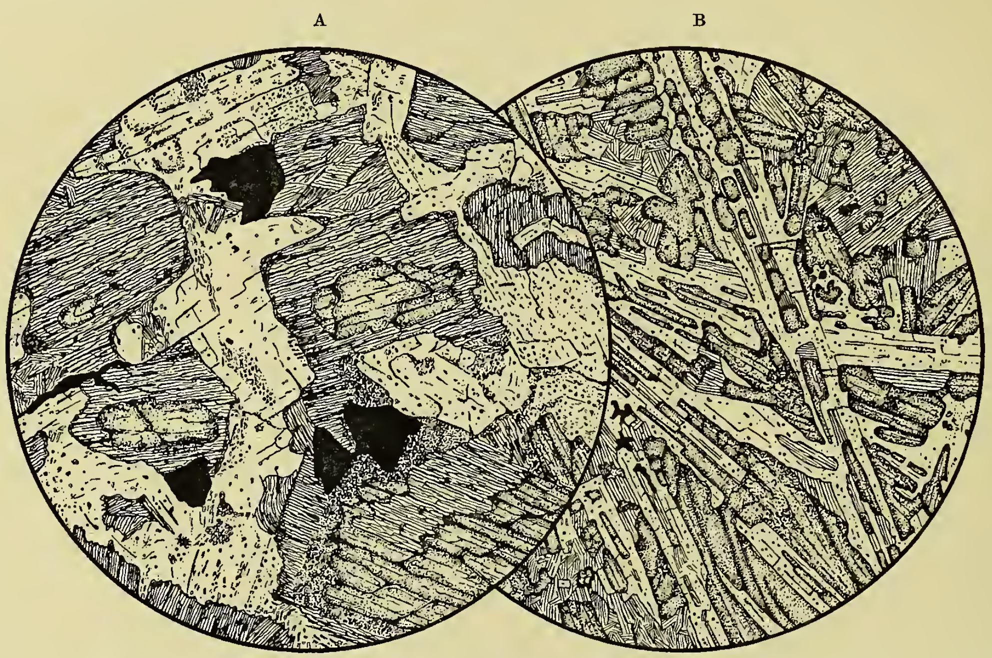
(4) Basalt, Lake Balaton, Tóti hegy, Komitat Zala. 'Jahresbericht d. Kgl. Ungarischen. Geolog. Anstalt.,' 1906, p. 338.

(5) Basalt, Little Ash Creek, Bradshaw Mts., Arizona. 'Geologic Atlas of United States,' folio 126, 1905, p. 7.

(c) HORNBLENDE-AUGITE-DOLERITE AND SIGNIFICANCE OF HORNBLENDE.

The third specimen analysed (St. 133, 15) is a small angular black fragment, which on a fractured surface has a slightly greenish appearance. The thin section is remarkable for its content of green fibrous hornblende, as well as augite and plagioclase. The felspar, occurring as moderately broad short laths (Text-fig. 4A), has for the most part crystallized

before the augite. It rarely exhibits twinning and has a variable composition, for some of the larger laths may be as basic as $Ab_{29}An_{71}$ ($\gamma = 1{\cdot}572 \pm 0{\cdot}002$), whilst others are as acid as oligoclase-andesine ($\alpha = 1{\cdot}546 \pm 0{\cdot}002$). Hornblende, sometimes occurring as a peripheral border to augite, has clearly been derived from that mineral, and has a refractive index $\beta = 1{\cdot}640 \pm 0{\cdot}002$, whilst $Z : c = 24°$. It is pleochroic from Z = faint blue-green to X = light yellowish-green. The colourless augite occurring as individual crystals and as kernels to the fibrous hornblende has $\gamma = 1{\cdot}709 \pm 0{\cdot}004$ and $\alpha = 1{\cdot}687 \pm 0{\cdot}004$, and the maximum extinction angle $Z : c = 37°$. A little iron-ore is present, and here and there a small patch of chlorite showing anomalous interference colours. Glass is absent in this rock.



TEXT-FIG. 4.—Hornblende-dolerite and variolotic basalt from the Carlsberg Ridge. A. × 68. Hornblende-augite-dolerite (St. 133, 15); compared with the other Carlsberg Ridge basalts this has a relatively coarse texture; the hornblende (wavy shading), derived from the augite, occurs as a peripheral border to that mineral as well as in individual crystals. B. × 68. Variolitic augite-basalt (St. 133, 12); the oligoclase occurs as thin laths in a roughly radiating fashion, and the chlorite (linear shading) is intimately associated with the augite.

The presence of green hornblende in this specimen is interesting, as it is the only specimen from the Carlsberg Ridge which contains that mineral. The absence of glass and the relative coarseness of the rock indicate that it cooled slower than those previously described, but yet it has not the coarse texture that is characteristic of gabbros. It would seem logical, both on textural considerations and from the presence of hornblende, to classify this rock with the dolerites in spite of the fact that it has a close chemical relationship to the associated basalts. A metamorphic origin might be urged by some for this rock, as the production of hornblende from augite is an established metamorphic process. But as hornblende, chlorite, albite and epidote are the normal products of low-grade regional metamorphism of basic igneous rocks (Wiseman, 1934), so it would be reasonable to expect, if the hornblende had a metamorphic origin, the felspar to be more albitic and to be associated with abundant epidote. Since this is not the case, a metamorphic origin

of the hornblende is suspect. On the other hand, it would be difficult to subscribe to the view that the hornblende is of intratelluric crystallization, for its occurrence as fibres projecting into the plagioclase makes such a contention untenable. To the author it would appear more reasonable to regard the hornblende as produced by end-stage reactions. Read (1935), in a recent paper on the gabbros from Haddo House district, Aberdeenshire, has described the production of a green fibrous amphibole by a post-magmatic modification of the original pyroxene, and it would seem that a similar reaction has taken place in the case of the Carlsberg Ridge specimen.

It would be a rational inquiry to ask why hornblende occurs in only one specimen from the Carlsberg Ridge and not in the other basaltic specimens of similar composition. Further, it might be suggested that the hornblende rock belongs to a different period of vulcanicity than the other basalts. Although such a contention cannot be definitely disproved, the close chemical resemblance between the basalts and dolerite from this station would favour a contemporaneous origin, or at least an origin belonging to the same igneous cycle. The moderately coarse texture of the hornblende-dolerite, when compared with those of the more normal basalts from this area, indicates, as has been mentioned previously, that the cooling history of this rock was different from those of the more normal basalts. Consequently the difference in texture implies a different habitat for solidification, and hence the possibility of end-stage reactions whilst the other specimens were unaffected.

The chemical composition of the hornblende-augite-dolerite is given in Table IV, column 1. The analysis is similar to the variolitic basalt (Table I, column 1) described on an earlier page, and the low potash is again a distinctive feature. It is noteworthy that in this rock there is no apparent oxidation of FeO to Fe_2O_3, and with this the small amount of uncombined water and the absence of glass in the original specimen is correlated. Lewis (1908) has described from the Palisades of New Jersey a basalt (column 2) with a comparable composition, apart from larger potash and total iron. The same difference is shown by a basalt from El Salto de San Anton, Mexico (column 3), which according to Guild (1906) contains olivine and an orthorhombic pyroxene. A chemically similar diorite described by Alvisi (1912) from Elba (column 4) has an almost identical amount of soda, but the potash is three times as great as in the hornblende-dolerite. It is interesting to note the similarity between the norms of the Elban diorite and the Carlsberg Ridge dolerite.

It is evident, then, from Table IV that, although rocks of similar composition occur in other regions of the world, yet no comparable analyses, which have extremely low potash content, are known. This again illustrates the abnormality of these rocks with regard to potash.

(*d*) Variolitic Basalt.

The fourth rock analysed from the Carlsberg Ridge is a fine-grained variolitic basalt. In thin section it resembles the variolitic basalt (St. 133, 8) previously described, the thin felspar laths occurring in a roughly radiating fashion (Text-fig. 4B). The felspar is an oligoclase with about 26% anorthite ($\gamma = 1{\cdot}548 \pm 0{\cdot}002$), and rarely exhibits lamellar twinning. Augite, occurring as small crystals between the felspar laths, has a very faint purple colour, and its refractive indices are $\alpha = 1{\cdot}679 \pm 0{\cdot}004$, $\gamma = 1{\cdot}728 \pm 0{\cdot}004$, whilst the extinction angle $Z : c = 50°$. A greenish chlorite, with positive elongation, is

TABLE IV.

	(1)	(2)	(3)	(4)
SiO_2	51·71	51·77	51·56	52·21
TiO_2	1·39	1·13	1·81	2·13
Al_2O_3	14·36	14·59	15·24	13·93
Fe_2O_3	1·91	3·62	2·73	3·62
FeO	6·68	6·90	5·99	6·01
MnO	0·14	0·05	0·15	—
MgO	8·28	7·18	8·30	7·56
CaO	9·90	7·79	7·67	10·24
Na_2O	3·33	3·92	3·74	3·30
K_2O	0·09	0·64	1·85	0·25
H_2O+	1·67	1·85	0·16	0·35
H_2O-	0·25	0·46	0·15	—
P_2O_5	0·13	0·18	0·47	—
CO_2	*Nil*	—	—	—
Inclusive	—	—	0·12	—
	99·84	100·08	99·94	99·60
Norms.				
Quartz	0·36	—	—	2·94
Orthoclase	0·56	3·89	11·12	1·67
Albite	27·77	33·01	31·44	27·77
Anorthite	24·19	20·29	19·18	22·24
Diopside	19·43	14·77	12·17	22·73
Hypersthene	19·81	16·88	6·81	12·48
Olivine	—	1·39	10·15	—
Magnetite	2·78	5·34	3·94	5·34
Apatite	0·34	2·13	1·24	—
Ilmenite	2·74	0·34	3·34	4·10

(1) Hornblende-augite-dolerite (St. 133, 15), Carlsberg Ridge, Indian Ocean. Analyst: J. D. H. Wiseman.

(2) Basalt, Springfield, New Jersey. 'N. J. Geol. Sur. Ann. Rep.,' 1908, p. 159.

(3) Basalt, El Salto de San Anton, Mexico. 'Amer. Journ. Sci.,' XXII, 1906, p. 170. In this reference the amount of potash is given as 1·25%, but Washington considers this an error, and he gives 1·85 as the corrected value.

(4) Diorite, Elba. 'Mem. Soc. Toscana di Sci. Nat.,' XXVIII, 1912, p. 205.

associated with the augite, its colour being quite distinct from the yellowish-green chlorite occurring in the other variolitic basalt (St. 133, 8). Most of the chlorite is secondary after augite. No original olivine occurs in the thin sections, nor does any of the chlorite have the appearance of arising from that mineral, though there is 13% of normative olivine in the rock. It may be that olivine was never represented, and in this connection it is not unusual to find olivine in the norm, whilst it is absent in the mode. With the addition of small patches of iron-ore and an occasional grain of yellowish epidote the rock is completed.

The composition of this variolitic basalt is given in Table V, column 1, and the high percentage of soda and the low potash is again characteristic. No oxidation of the ferrous oxide appears to have taken place, and in this connection it is interesting to emphasize the absence of glass and the small amount of uncombined water. In column 2 the analysis of an essexitic-gabbro described by Lacroix (1909) is recorded, and apart from the higher potash content has a similar composition. A further comparison can be made with a basalt described by Washington (1909) from Graham Island, near Sicily (column 3), but the potash is much higher. In the basalt from Graham Island and the gabbro from Cantal the amount of combined water is considerably smaller than that occurring in the variolitic basalt—a feature which is no doubt connected with the occurrence of chlorite in the variolitic basalt.

TABLE V.

	(1)	(2)	(3)
SiO_2	49·43	49·10	48·97
TiO_2	1·94	2·92	3·95
Al_2O_3	15·04	15·75	16·37
Fe_2O_3	2·21	1·00	1·33
FeO	7·39	8·80	8·56
MnO	0·23	—	0·06
MgO	8·40	6·35	6·22
CaO	6·69	8·56	7·49
Na_2O	4·45	4·47	4·09
K_2O	0·11	1·91	1·72
H_2O+	3·16	0·75	0·38
H_2O-	0·86	—	0·08
P_2O_5	0·19	0·22	1·04
CO_2	*Nil*	—	—
Inclusive	—	—	0·08
	100·10	99·83	100·34
Norms.			
Orthoclase	0·56	11·12	10·01
Albite	37·73	24·10	34·58
Anorthite	20·57	16·96	21·13
Nepheline	—	7·67	—
Diopside	9·61	19·26	7·91
Hypersthene	6·38	—	—
Olivine	13·00	12·34	14·44
Magnetite	3·25	1·39	1·86
Apatite	0·34	0·67	2·35
Ilmenite	3·65	5·62	7·45

(1) Variolitic-augite-basalt (St. 133, 12), Carlsberg Ridge. Analyst: J. D. H. Wiseman.

(2) Essexitic-Gabbro, Font-des-Vaches, Cantal, France. 'C. R.,' CXLIX, 1909, p. 546.

(3) Basalt, Graham Island, near Sicily. 'Amer. Journ. Sci.,' XXVII, 1909, p. 138.

IV. GENERAL CHEMICAL FEATURES OF THE CARLSBERG RIDGE ROCKS.

The analyses of three basalts and one dolerite are reproduced together in Table VI for easier comparison, the Carlsberg Ridge analyses being arranged in order of increasing silica percentage. Inspection of these four analyses reveals that, whilst there is a slight variation in the silica percentage, the alumina remains practically constant. All four analyses are characterized by a moderately high soda percentage, which varies between 3·19 and 4·45, whilst the potash is very low, ranging from 0·21% to 0·04%. The total iron content is, perhaps, smaller than that usually occurring in basalts, but in one analysis there has been an oxidation of ferrous iron to the ferric condition, and with this the 2·46% of uncombined water is correlated. With regard to the lime and magnesia there is no systematic variation, for the lime may be greater or smaller than the magnesia. Titania, phosphorus and manganese occur in amounts normal for basalts, whilst the considerable H_2O+ is related to the presence of chlorite. Briefly, then, the chemical investigation bears out the relationship of these rocks one to each other, and emphasizes their dominant characteristic, namely, high soda and very low potash.

Table VI.

	(1)	(2)	(3)	(4)	(5)
SiO_2	47·58	49·43	51·71	52·24	48·58
TiO_2	2·10	1·94	1·39	1·83	1·77
Al_2O_3	15·05	15·04	14·36	15·02	14·58
Fe_2O_3	6·74	2·21	1·91	2·93	1·89
FeO	4·42	7·39	6·68	6·31	7·65
MnO	0·14	0·23	0·14	0·14	0·46
MgO	5·71	8·40	8·28	6·01	6·36
CaO	10·97	6·69	9·90	8·73	9·80
Na_2O	3·19	4·45	3·33	4·02	4·02
K_2O	0·04	0·11	0·09	0·21	0·43
H_2O+	0·99	3·16	1·67	2·25	2·93
H_2O-	2·46	0·86	0·25	0·50	0·68
P_2O_5	0·23	0·19	0·13	0·20	0·19
CO_2	*Nil*	*Nil*	*Nil*	*Nil*	1·00
Inclusive	—	—	—	—	0·29
	99·62	100·10	99·84	100·39	100·63

(1) Variolitic basalt (St. 133, 5), Carlsberg Ridge. Analyst: J. D. H. Wiseman.
(2) Variolitic-augite-basalt (St. 133, 12), Carlsberg Ridge. Analyst: J. D. H. Wiseman.
(3) Hornblende-augite-dolerite (St. 133, 15), Carlsberg Ridge. Analyst: J. D. H. Wiseman.
(4) Augite-basalt (St. 133, 8), Carlsberg Ridge. Analyst: J. D. H. Wiseman.
(5) Spilite, Mullion Island, Cornwall. "Geology of Lizard and Meneage," 'Mem. Geol. Sur. E. & W.,' 1912, p. 185.

In the above discussion we have emphasized the rarity of comparable analyses. On account of this it might be urged that the low potash content is not an original feature, but is due to a possible leaching effect of the sea-water. Fortunately, in addition to the difficulty of accounting for the preferential removal of the alkalis there is some definite evidence on this point, for at Station 166 one or two specimens of angular basalt were found in the trawl consisting mainly of manganese nodules. An analysis has been made of a variolitic basalt from this station. The potash content is 0·57%, whilst the soda is 2·34, and since this basalt contains appreciable potash it is inconceivable to imagine preferential leaching at one station and not at the other when both rocks came from similar depths. It is therefore concluded that the low potash content at Station 133 represents an original feature. Whether this is a characteristic of the Carlsberg Ridge as a whole is a matter for future work, but the occurrence of a variolitic basalt with appreciable potash from Station 166 would indicate that such a feature is not common to the whole Indian Ocean.

It might be considered from the association of soda-rich, potash-poor basalts with deep-sea deposits that they owe their peculiar chemical composition to hydrothermal replacements under the influence of heated sea-water, but as will be shown subsequently, there are objections which make such an hypothesis improbable. It would therefore seem that some petrogenetic theory other than alteration by heated sea-water or by leaching is required.

V. RELATION TO THE SPILITIC SUITE.

In composition the Carlsberg Ridge rocks have some resemblance to spilites, and in Table VI, column 5, the composition of the Mullion spilite (Flett and Hill, 1912*b*) is recorded. According to Dewey and Flett (1911) the spilitic rocks are, as a rule, very much decomposed and the felspars are always rich in soda. The principal constituent is felspar; next in importance is augite of pale brown colour whilst, in addition, some of them have contained a fair amount of glassy base, which is devitrified and decomposed. A large number of spilites are variolitic and the augite occurs as irregular masses exhibiting a sub-ophitic texture. The Carlsberg Ridge basalts agree in general with this description, and in addition they have a chemical resemblance to rocks of the spilitic suite, as they are all rich in soda, but they are, on the whole, much poorer in potash than normal spilites. Mineralogically the felspar is never more acid than basic oligoclase, whilst in spilites it is typically albite-oligoclase. From these considerations it is reasonable to consider these rocks as basalts with spilitic affinities.

The occurrence of such rocks at the bottom of the Indian Ocean is significant, as spilites are frequently regarded as submarine. A brief survey of the literature reveals that spilites and keratophyres are frequently associated with marine sediments in such a manner as to suggest a submarine eruption. Such rocks occur in Cornwall (Flett and Hill, 1912*a*), Devon (Flett and Dewey, 1912), Wales (Jones and Cox, 1913), Scotland (Peach and Horn, 1899), Australia (Benson, 1913), Germany (Brauns, 1909), Czechoslovakia (Kettner, 1917), Norway (Carstens, 1924; Goldschmidt, 1916), Sweden (Beskow, 1927*a*), East Indies (Verbeek, 1905), and America (Knopf, 1918); but the keratophyres of Nevada are, according to Knopf (Knopf, 1921), subaerial, and so are the skomerites of Wales (Thomas, 1911). From this brief presentation it may be judged that although the spilitic

rocks are mainly the products of submarine eruptions, they are very rarely subaerial. A similar conclusion has been recently emphasized by Gilluly (Gilluly, 1935) when discussing the spilites of eastern Oregon. The frequency of spilites with marine sediments would favour a submarine origin for the Carlsberg Ridge rocks, but a fuller discussion of this problem will be left for a subsequent page.

It might be urged by some that the occurrence of basalts with spilitic affinities on the Carlsberg Ridge supports Beskow's (Beskow, 1927*b*) contention that the spilites are produced by hydrothermal replacements under the influence of heated sea-water. Beskow considers that the major chemical change is the leaching of potassium, and an increase of soda largely of marine origin. Daly (1914) supports a rather similar idea, for he regards the intense albitization as being produced by the eruption of lavas through wet sediments, and he invokes the action of resurgent water for the transference of soda. Although it is not within the province of this paper to discuss the spilitic problem, it is suggested that the submarine rocks investigated from the Indian Ocean give little support for the hydrothermal action of heated sea-water. Thus, in a rock collected at a depth of 744 fathoms near to Providence Reef only 1·72% of soda is present, whilst the potash (0·95%) is quite appreciable. As stated in the original paper (Wiseman, 1936*b*), this rock has a submarine origin, and hence according to Beskow there should be a possibility of hydrothermal action. But such a process cannot have taken place, for the alkali content is normal. Similarly, in a previously mentioned variolitic basalt from Station 166 the alkali content is normal; the composition of this rock is recorded in Table VII, column 2, but the petrographical description will be reserved for a later publication. It would therefore seem, both from the above evidence and from other oceanic rocks described in the literature, that submarine basaltic eruptions do not of necessity involve the production of spilites. From this it would seem unnecessary to invoke the action of heated sea-water to account for the spilitic tendency of the Carlsberg Ridge basalts, but rather that the soda-rich potash-poor feature is an inherent tendency of the magma itself. It is not suggested that the oligoclase crystallized out of the molten magma as such, for as demonstrated by Eskola (1925), the subophitic nature of the pyroxene opposes such a contention, but that the albitization of a more basic plagioclase was a property of the magma itself and did not require the aid of external agencies. As to the period of albitization, it must have taken place before the eruption of the small fragments, and hence presumably in the volcanic neck.

VI. COMPARISON WITH OTHER ROCKS.

(*a*) The Indian Ocean.

In Table VII one new analysis of a rock from the floor of the Indian Ocean is given; column 1 represents the average of the three unoxidized Carlsberg Ridge rocks, column 2 a new analysis of a variolitic basalt from Station 166, whilst column 3 is a limburgite from Providence Reef. In the two latter analyses the ferrous iron has been largely oxidized to the ferric condition. Although the chemical evidence is very limited, the analyses of the first three columns support the hypothesis of a basic substratum to the Indian Ocean, and from the available evidence it would seem that the soda-rich potash-poor basalts are not characteristic of the area as a whole, but are a local variety of a basaltic type.

TABLE VII.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
SiO_2	51·12	46·55	40·10	48·62	46·49	48·22	50·61
TiO_2	1·72	1·17	3·72	2·00	2·86	2·72	1·91
Al_2O_3	14·81	18·13	14·54	17·69	14·28	14·74	13·58
Fe_2O_3	2·35	5·89	11·27	3·76	2·90	2·24	3·19
FeO	6·79	4·70	3·37	5·76	9·43	9·38	9·92
MnO	0·17	0·09	0·13	—	0·16	—	0·16
MgO	7·56	3·82	11·48	5·25	8·87	7·01	5·46
CaO	8·44	13·69	10·89	8·76	11·23	12·26	9·45
Na_2O	3·93	2·34	1·72	4·45	2·74	2·23	2·60
K_2O	0·13	0·57	0·95	2·27	0·48	0·89	0·72
H_2O+	2·36	1·33	—	0·75	0·20	0·06	1·70
H_2O-	0·54	1·03	—	0·29	0·52		0·43
P_2O_5	0·14	0·92	1·39	0·59	0·27	0·35	0·39
CO_2	*Nil*	*Nil*	—	—	—	—	—
Inclusive	—	0·10	0·44	—	—	—	—
	100·06	100·33	100·00	100·19	100·43	100·13	100·12

(1) Average of three unoxidized rocks from the Carlsberg Ridge.
(2) Variolitic basalt, Station 166. Analyst: J. D. H. Wiseman.
(3) Limburgite, Providence Reef. Recalculated without water and calcite. 'Trans. Linn. Soc. Zool.,' ser. 2, XIX, p. 440.
(4) Basalt, Tonnere Cliff, Rodriguez. 'Minéralogie de Madagascar,' III, 1923, p. 239.
(5) Average of two basalts from Mauritius. 'Quart. Journ. Geol. Soc.,' LXXXIX, 1935, p. 5, and 'Minéralogie de Madagascar,' III, 1923, p. 239.
(6) Average of eight basalts from Réunion.
(7) Average of eleven Deccan Trap analyses. 'Bull. Geol. Soc. Amer.,' XXXIII, 1922, p. 774.

According to Farquharson, as I have mentioned before, Rodriguez lies on a continuation of the Carlsberg Ridge, and if this is so it would be reasonable to expect a relation between the rocks of this island and those from Station 133. Although the "Venus" Expedition (Balfour, 1879) called at Rodriguez, no detailed description of the lavas is given in their reports, but Lacroix (1923*c*) describes the island as consisting of olivine-basalts which occasionally contain nepheline, and he gives an analysis of a basalt (Table VII, column 4). If this analysis is representative of the island, then the lavas of Rodriguez are much richer in potash than those from the Carlsberg Ridge station. Consequently the available evidence would indicate that the basalts are of a different type to those of the Carlsberg Ridge. This observation, if true, is of some significance in any discussion on the regional extent of the Carlsberg Ridge, for frequently igneous rocks erupted within a period of magmatic activity and on a given tectonic line show a certain community of chemical and petrographical features. It might be reasonably expected, then, that if Rodriguez lies on a direct continuation of the Carlsberg Ridge, the basalts would be characterized by low potash; but this is not the case, and consequently the petrological evidence does not favour such a prolongation of the ridge. A critical examination of the hydrographical evidence in favour of placing Rodriguez on a continuation of the

Carlsberg Ridge reveals only two soundings between latitude 5° S. and the island, and hence too much reliance cannot be placed on a contention based on such meagre hydrographical evidence. If, on the other hand, Rodriguez is not on the Carlsberg Ridge, then the different character of its basalts finds a natural explanation.

The available soundings suggest a deep depression between Rodriguez and Mauritius, and the Antarctic bottom drift which, according to the results of the Murray Expedition, comes up between these islands, gives support to such a contention. It is possible therefore that Rodriguez and Mauritius lie on different structural lines, but Mauritius and Réunion are probably on the same bank. Whether these two islands lie on a continuation of the Seychelles bank is a matter for future confirmation, but the work of the Percy Sladen Trust Expedition (Gardiner, 1907) to the Indian Ocean indicates the possibility of a channel intersecting this bank.

Mauritius, situated 100 miles E.N.E. of Réunion, is essentially volcanic. Several investigators—Bory de Saint Vincent (1804), Darwin (1845), Clark (1867), Drasche (1878), Haig (1895)—have described this island, but it was left for Shand (1935) and Lacroix (1923*c*) to study the petrology of the lavas. The lavas are mostly olivine-basalts of normal character, but in addition trachyte occurs at La Selle. Washington (1930*b*) has remarked on this association for the Intra-Pacific volcanoes, for he states that " there are now known to be very few islands or island groups in the Pacific that are wholly basaltic and without trachyte or basanite ". A similar association has been recorded on Réunion (Lacroix, 1923*b*), Madagascar (Lacroix, 1923*a*) and Christmas Island (Smith, 1926). In Table VII, column 5, the average of two basalts from Mauritius is given, and this column is remarkably similar to the average basalts from Réunion (column 6). Further, the compositions of the trachytes are alike. From these facts it would seem that the rocks of Mauritius and Réunion are comparable—a conclusion agreeing with the hypothesis that these islands are on the same structural bank. In the absence of trachytic types the rocks from Station 133 obviously differ from those of Mauritius and Réunion, and, furthermore, are poorer in potash. To the author it would seem premature to compare, as Lacroix has done, Rodriguez with Mauritius, but it is perhaps significant that no trachyte was brought back in the collections of the " Venus ", whilst the analysed basalt is richer in alumina than the average basalts from Mauritius and Réunion.

Some oceanographers (Schott, 1935) consider that the islands of New Amsterdam, St. Paul, Kerguelen and Heard lie on a continuation of the Indian Ocean ridge, but such an hypothesis must, owing to the scarcity of soundings, be relegated to the realm of speculation. It is interesting, however, to compare the petrology of these islands with the rocks from Station 133. New Amsterdam is situated south-east of Réunion and north-east of Kerguelen, whilst St. Paul is on the same meridian, but 50 miles further south. All the islands are volcanic, and were studied in 1866 by Hochstetter (1866), and more recently by Phillipi (1905). New Amsterdam is completely basaltic, and Lacroix (1923*d*) reports in two recent analyses 0·79 and 0·51% K_2O ; so it is evident that the basalts of this island contain appreciable potash. In the reports of the German expedition a volcanic " bomb " is described from a depth of 2414 metres at a station 114 miles north-east of that island. It is significant that in the analyses of this " bomb ", incomplete as they are, 1% of potash occurs, giving support to our contention that the low potash content of the Carlsberg Ridge rocks is not related to the action of sea-water. St. Paul is geologically more complicated, but in the eight available analyses the potash is never below 0·67%.

Kerguelen comprises a great number of small islands and is situated 70° E. and 50° S. The islands are made up, apart from a bed of lignite, of basalts, trachytes and phonolites, and the smallest potash content in the fourteen available analyses is 0·85%. Heard Island, situated about 300 miles S.E. of Kerguelen, was investigated by the "Challenger" Expedition, the rocks being basalts, trachytes and limburgites, all of which contain appreciable potash (0·95 to 3·22%). It may be judged even with this cursory presentation that the rocks of New Amsterdam, St. Paul, Kerguelen and Heard have little resemblance to those from the Carlsberg Ridge.

(*b*) The Deccan Traps.

The great continent of Gondwana has appeared on many maps since Suess first named it, and it has furnished convenient paths for the wandering floras and faunas. The hypothesis that the oceanic basins may have once been extensive continents was conceived before the theory of isostasy. According to this theory if the continents, consisting of relatively light rock, sank several thousand feet, they would produce a negative gravity anomaly, which is contrary to the facts so far as they are known, for the ocean basins are practically in equilibrium, or with a slight tendency to a positive anomaly. Nor can it, as Willis (1932) pointed out, be suggested that Gondwanaland consisted of relatively heavy basalt, which has now sunk to its equilibrium level, for such a mass would, when it rose above the waters, constitute a very heavy load on the earth's crust. The difficulty might possibly be overcome by postulating the association of basaltic and granitic types on Gondwanaland, and in connection with its possible constitution it is interesting to compare the rocks from Station 133 with the Indian basalts.

The Deccan traps, extruded towards the end of the Cretaceous or possibly in Lower Eocene times, cover an area of more than 200,000 square miles in central and western India. At Bombay Oldham (1893) gives a minimum thickness of 7000 ft., and it is unlikely that such a thickness of lavas would cease abruptly on the coast without some continuation under the sea. Washington (1922*a*), in a valuable contribution, has made a detailed chemical study of the Deccan traps involving eleven new rock analyses, and according to that investigator the most striking feature of the series is their uniformity in composition. In eight analyses the silica varies from 48·6 to 50·1, whilst three have higher silica. The larger group is characterized by high iron oxides, varying from 12·6 to 14·5%. Corresponding to this high FeO the amount of MgO is low, whilst the potash is appreciable in all the analyses. In Table VII, column 7, Washington's average Deccan trap is recorded, and compared with the average Carlsberg Ridge basalt it is much richer in total iron and potash, but poorer in magnesia and soda. There is therefore no close chemical similarity between the Deccan traps and the rocks from Station 133, and consequently the author cannot concur with Coates's (1934) tentative correlation of the rocks from Station 133 with the Deccan traps. It is significant to mention in this connection that the radium content of the Deccan traps is very much greater than in the rocks from Station 133.

From the above considerations the author is led to believe that if the rocks from Station 133 and 166 represent remnants of Gondwanaland, then the composition of this hypothetical continent was different from the Deccan traps. The thesis that the rocks

at Stations 133 and 166 are of submarine origin has already been advanced, and it has been suggested that the association of igneous rocks with a major tectonic structure, as well as their semi-spilitic nature (which is so characteristic of basalts from geosynclinal areas), give valuable confirmatory evidence to such an hypothesis. In addition, the subaqueous oxidation of the variolitic basalt appears, to the author, to support this contention, for it is argued that if the basaltic fragments were remnants of Gondwanaland the oxidation would in all probability be subaerial. Subaerial oxidation has, according to Pirrson, taken place in the igneous platform of Bermuda Island, where an oxidized zone of considerable thickness rests on unoxidized basalts. It is significant that in the petrographical descriptions by Pirrson and Thomas (1914*b*) no record is made of glass in the unoxidized melilite-basalts, lamprophyres, monchiquites and keratophyres. Pirrson considers that the oxidized products were formed from similar petrological types, so in this locality profound subaerial oxidation took place in spite of the fact that the rocks originally contained little or no glass. Similarly, Merrill (1897), when discussing the weathering of diabases, mentions that oxidation of the iron is a characteristic feature, but he makes on limitation of this process being dependent on the presence of glass, whilst a similar conclusion may be deduced from the analyses given by Harrison (1933) in his recent study on the tropical weathering of igneous rocks. It is a fair conclusion from these examples to regard subaerial oxidation as taking place quite independently of the presence of glass, and it is suggested that if such a process had affected the Carlsberg Ridge specimens, then oxidation would be common to them all. But this is not the case, for of the four analysed specimens, three show no trace of oxidation, and only one specimen, containing original glass, has been affected. We conclude from this evidence that the oxidation was submarine, and consequently the specimens, in all probablity, do not represent remnants of Gondwanaland. In connection with subaqueous oxidation, it is interesting to emphasize that in the rocks so far examined glass is essential for oxidation —a feature connected with the limited oxidizing power of sea-water and the instability of the metastable glassy phase.

(*c*) East Africa.

Tertiary lavas are well developed in East Africa, and as Gregory (1921) suggests that the eruption of the Kapiti Phonolite (late Cretaceous) probably coincided with the foundering of the Indian Ocean, it is interesting to inquire whether there is any geological resemblance between this region and the Carlsberg Ridge. Furthermore, as the Carlsberg Ridge has a superficial resemblance to the reflected image of the African Rift, it might be urged, by some, that the two structures are tectonically related, and consequently the lavas might exhibit similar petrological characteristics. Among the investigators of the African lavas are Gregory (1900), Prior (1903), Neilson (1921), Smith (1931), Holmes (1932) and Jérémine (1935), and the work of these authors indicates that the rocks are of a distinctly alkaline nature. As potash-poor types are unknown it is concluded that the rocks of this region do not resemble the Carlsberg Ridge, and in order to emphasize this dissimilarity an average analysis of twenty-four East African basalts has been compiled (Table VIII, column 2). Compared with the Carlsberg Ridge specimens the African basalt is typically poorer in silica and soda, but richer in potash and total iron.

Table VIII.

	(1)	(2)	(3)	(4)	(5)
SiO_2	51·12	43·12	49·54	50·63	50·06
TiO_2	1·72	3·04	0·78	1·63	1·96
Al_2O_3	14·81	13·77	16·47	15·82	15·51
Fe_2O_3	2·35	4·75	2·30	4·44	3·88
FeO	6·79	7·98	7·55	5·79	6·23
MnO	0·17	—	0·19	0·04	0·15
MgO	7·56	8·07	11·43	5·79	6·62
CaO	8·44	11·13	7·91	7·36	7·99
Na_2O	3·93	3·07	2·62	4·27	4·00
K_2O	0·13	2·58	0·30	2·31	2·10
H_2O+	2·36	1·98	0·95	1·47	1·16
H_2O-	0·54		0·27		
P_2O_5	0·14	0·52	0·08	0·43	0·25
CO_2	*Nil*	—	—	—	—
Inclusive	—	—	0·21	0·07	0·08
	100·06	100·01	100·60	100·05	100·00

(1) Average of three unoxidized basalts from the Carlsberg Ridge.

(2) Average of twenty-four alkali-basalts from East Africa. Localities: Mikeno, Visoke, Nirogongo, Kitelema, Bolingo, Katwe, Mukira, Adolphe Frédéric, Goma, Nyamunaka, Fort Ternan, Rogate River, Nyeri Road, Settima Scarp, Nyuki Scarp, Nguruman Scarp, Lodwar, Kakalai, Lokitaung, Naivasha.

(3) Augite-olivine-basalt, Atlantic Ocean, 1° 56′ S., 12° 40·7′ W. 'Chemie der Erde,' V, 1930, p. 83.

(4) Average composition of Atlantic floor. 'Ann. Rep. Smithson. Inst.,' 1920, p. 307.

(5) Average composition of Pacific floor. 'Ann. Rep. Smithson. Inst.,' 1920, p. 307.

(*d*) Other Oceanic Regions.

The lavas of volcanic oceanic islands, which are generally assumed to represent the material below, furnish for the most part the only direct evidence about the rocks that form the Atlantic and Pacific Ocean floors. Seismological evidence indicates that oceanic foundations are largely basaltic, for according to Angenheister (Gutenberg, 1932), the velocity of the longitudinal wave near the surface of the sub-Pacific crust is 6·5 to 7·0 kilometres per second, which is appropriate to crystallized basalt, whilst Hiller's study of the transmission of one type of surface wave under the Pacific leads to a like result, for he finds the velocity 3·69 kilometres per second (Hiller, 1927). Further, the work of Meinesz (1932) in the Pacific has made it exceedingly probable that the whole basin is in isostatic equilibrium, and suggesting thereby the existence of heavier rocks below, with considerable variations in density or chemical composition, or both. The basic substratum concept is supported by such authorities as Joly (1925*b*) and Jeffries (1929), whilst more recently Daly (1933) has suggested that in the open Pacific there is 80 kilometres of gabbro, and below that a substratum of vitreous basalt. Washington (1929) has emphasized that the intra-Pacific volcanoes are basaltic, but with certain peculiarities.

Many of the Pacific lavas are so rich in olivine that they have been given a special name-" oceanite "—and the same author has remarked on their association with alkaline lavas. In general basalts predominate to such an extent that the alkaline lavas constitute not more than 1 or 2% of the Pacific Rocks, but their presence throughout the whole basin is one of the striking characteristics. Washington considers that the Atlantic basin is petrographically more complex, and he distinguishes three regions: firstly, the Mid-Atlantic Ridge, secondly the islands (Madeira, Canary and Cape Verde Islands) which lie on the western continental shelf of Africa, and thirdly the Arctic Islands, Iceland, Jan Mayen, the Faröes, etc.

The Mid-Atlantic Ridge, which represents a long narrow submarine mountain range, extends from near Iceland in the north to about 57° S. latitude, and includes in its course the Azores, Ascension, Tristan da Cunha, and the very significant St. Paul's Rocks. The lavas of these ridge islands, apart from St. Paul's, which is a metamorphosed dunite (Washington, 1930*a*), resemble those of the intra-Pacific islands, as they are predominantly basaltic, with the characteristic association of trachytes. In the Atlantic, however, basalts rich in olivine are much less abundant, whilst the alkaline lavas are of more frequent occurrence. St. Helena, situated 900 kilometres east of the summit of the Mid-Atlantic Ridge, consists of a volcanic cone rising from the sea floor at a depth of 4200 metres. Daly (1927), in a recent investigation, states that St. Helena is largely basaltic, whilst the remainder is phonolitic. In four basalt analyses given by that author the potash content varies between 0·84 and 1·37%, whilst the total iron is comparable to that occurring in normal plateau basalts. Ascension (Smith, 1930; Daly, 1922) is largely composed of olivine basalts, but trachytes, obsidians and rhyolites occur. Of considerable importance are the granitic and syenitic xenoliths, which suggest that the Ascension cone rests on some older foundation. Esenwein (1929) gave an account of the petrology of the Azores. These islands are characterized by the usual association of basalts and trachytes, and in several new analyses the potash content is normal, whilst the iron is rather high.

It is a natural inquiry to ask whether the basalts of such islands, derived from eruptions of the central type, are really representative of the basic substratum. Although there is at present insufficient evidence to answer this question, the evidence obtained by the " Meteor " Expedition (Correns, 1930*b*) about the Mid-Atlantic Ridge is significant, for a basaltic rock containing augite, olivine and bytownite was dredged up from a depth of 2000 metres at 1° 56′ S., 12° 40′ W. The analysis of this submarine basalt is reproduced in Table VIII, column 3, and compared with the average basalts from St. Helena, Ascension and the Azores it is considerably poorer in total iron, but richer in magnesia. Further, on the basis of this one analysis it would seem that, although the Carlsberg Ridge specimens have comparable total iron, they are poorer in alumina and magnesia than the submarine Mid-Atlantic Ridge.

The average composition of the Atlantic floor derived by Washington (1920) from seventy-two analyses is given in Table VIII, column 4, and apart from the characteristic higher potash, this average resembles the Carlsberg Ridge rocks, whilst a similar remark applies to the composition of the Pacific floor (Table VIII, column 5) derived from fifty-six analyses. It is unfortunate that Washington does not record the relative number of basalts used in computing his averages, but the high potash and the low iron is no doubt partially related to the inclusion of trachytes and related rock types. We may judge

from these oceanic comparisons that although the basalts of the Carlsberg Ridge are different from many of the basalts of the Atlantic and Pacific Islands, they have, apart from the lower potash, a comparable composition to Washington's average rocks from these regions.

(e) Plateau Basalts.

Although there is little agreement among geophysicists concerning the earth's interior, the concept that the continental crust is floating on a universal substratum of sima, basaltic, or gabbroic in composition, meets with fairly general acceptance. It is generally assumed that the average composition of the basaltic substratum is similar to that of the plateau basalts (Joly, 1925*a*), and that the deeper ocean floors, being for the most part devoid of the lighter outermost crust, represent the basaltic substratum (Wegener, 1924). It is therefore of some interest to inquire whether the Carlsberg Ridge specimens have similar chemical characteristics to the plateau basalts. In 1922 Washington (1922*b*) gave a summary of the Deccan, Oregonian, Thulean, Patagonian and Palisadian plateau basalts, and we have in the foregoing pages compared the Deccan Traps with the Carlsberg Ridge, and noted that the former are much richer in total iron and potash, but poorer in soda. It is significant that this feature is common to all Washington's average plateau lavas, as will be readily seen from an inspection of Table IX, which is abbreviated so as to show only the essential constituents.

Table IX.

	(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
Fe_2O_3 . .	2·35	6·74	5·89	3·19	2·37	3·58	3·41	4·05	3·59
FeO . .	6·79	4·42	4·70	9·92	11·60	9·38	8·58	9·19	9·78
Na_2O . .	3·93	3·19	2·34	2·60	2·92	2·90	2·92	2·22	2·59
K_2O . .	0·13	0·04	0·57	0·72	1·29	1·01	0·72	0·59	0·69

(1) Average of three unoxidized specimens from the Carlsberg Ridge.
(2) Oxidized variolitic basalt from Carlsberg Ridge.
(3) Oxidized variolitic basalt from Station 166.
(4) Average Deccan basalt. 'Bull. Geol. Soc. Amer.,' XXXIII, 1922, p. 797.
(5) Average Oregonian basalt. *Op. cit. supra.*
(6) Average Thulean basalt. *Op. cit. supra.*
(7) Average Palisadian basalt. *Op. cit. supra.*
(8) Average of seven analyses of Plateau Magma type from Mull.
(9) Average of world plateau Magma. 'Igneous Rocks and Depths of the Earth,' New York, 1933, p. 201.

The available evidence would suggest therefore that the floor of the Indian Ocean is characteristically different from the plateau magmas of the world. It is possibly confirmatory of this hypothesis that the basalt dredged from 2000 metres by the "Meteor" Expedition contains low total iron (Table VIII, column 3), and that Washington's averages for the Atlantic and Pacific floors (Table VIII, columns 4 and 5) show a similar feature as well as high soda. It is significant that in 1926 Washington (1926), when commenting on recent analyses from the Hawaiian Islands, states, "There are greater differences between them (*i. e.* the lavas of Hawaii and the Leeward Islands)

and the Deccan traps or plateau basalts, shown chiefly in higher silica and iron oxides and lower magnesia of the latter ".

Objections can be raised against this suggested difference between the average plateau magma and the floor of the Indian Ocean on the score of the few analyses, but taken in conjunction with the analyses from other oceans, it may be considered a fair indication of its nature. In any case these analyses are the only ones as yet available, and the indications offered by them are of interest, provided their tentative character is kept in mind.

VII. SUMMARY AND CONCLUSIONS.

In the foregoing pages petrographical descriptions and chemical analyses have been given of four Carlsberg Ridge rocks dredged from a depth of 3385 metres (St. 133, 1° 25′ 54″ S., 66° 34′ 12″ E.), as well as an analysis of a variolitic basalt from Station 166 (6° 55′ 18″ N., 67° 11′ 18″ E.). The specimens from Station 133 are, for the most part, angular, but some are more rounded and have a coating of manganese nodule material. Three of the described rocks are basalts, whilst one is a hornblende-augite-dolerite. Chemically they have some spilitic affinities, and are characterized by low total iron, moderately high soda and very low potash. The possibility of the alkali content being related to the action of sea-water is discussed, and it is suggested that the high soda low potash feature represents an inherent tendency in the parental magma.

The Carlsberg Ridge rocks differ both petrographically and chemically from the basalts of Rodriguez, and it is indicated that these rocks give little support to Farquharson's suggestion that this island lies on a continuation of the Carlsberg Ridge.

It is concluded that the basalts from the floor of the Indian Ocean are not sunken representatives of the Deccan traps, for they are too poor in total iron and potash. Similarly the hypothesis that they are remnants of Gondwanaland is rejected, for the rocks have no close resemblance to the basalts from neighbouring regions ; secondly, the oxidation is subaqueous and not subaerial, as might reasonably be expected if they were remnants of a former continent ; and thirdly, their association with a major structural feature gives confirmatory evidence to a submarine origin.

Apart from the low potash, the Carlsberg Ridge specimens are comparable to average rocks from the Atlantic and Pacific Oceans, and the available evidence would suggest that the basaltic substratum of the Indian Ocean differs from the Plateau magmas of the world by a lower total iron content. The geophysical significance of this does not seem to have been previously appreciated.

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IX. APPENDIX: THE RADIUM CONTENT OF SOME SUB-OCEANIC BASALTS FROM THE FLOOR OF THE INDIAN OCEAN.

By J. H. J. POOLE, Sc.D.

THROUGH the kindness of Dr. J. D. H. Wiseman I have been enabled to measure the radium content of some basalt specimens dredged up from the floor of the Indian Ocean. The results are of some interest, since, as far as I know, this is the first occasion on which basalt specimens from such depths have been available for radium content measurements. It is hoped also to determine their thorium content at some future date, but all radio-active measurements show that a rock deficient in radium is also deficient in thorium, so that the low values of radium content obtained for these basalts may be taken to indicate a low thorium content also, pending exact measurements.

The procedure employed for measuring the radium content of the basalts was Prof. Joly's original electric furnace method, in which the rock powder is fused with a mixture

of alkali carbonates and a small quantity of boric acid in an electric furnace at about 1100° C. During this process the rock is decomposed with the evolution of a large quantity of CO_2 and any radon contained in the rock is liberated. The CO_2 is absorbed by soda-lime and the radon transferred to a previously standardized gold leaf electroscope. By observing the increase in the rate of leak of the electroscope, the amount of radium present in the rock can be estimated. Usually about 8 g. of rock is used for each determination. This method has been previously fully described (1).

All the precautions mentioned in the former papers, such as freeing the carbonates and boric acid from radon by solution in water and evaporation to dryness immediately before use in the furnace, were adopted. The type of electroscope employed, however, was slightly modified, the container of the gold leaf system being made of aluminium instead of glass, as previously. Theoretically this should be better, as in a glass envelope there is a possibility of error due to an irregular distribution of electric charge on the dry inner surface of the glass, but actually no difference in the behaviour of the electroscope could be detected. This is probably due to the fact that, for the excessively small ionization currents measured, the glass acts as a fairly good conductor either through conduction or displacement currents. The electroscope was standardized as formerly by adding a known amount of uraninite dissolved in borax glass to the rock powder. Its constant was $0{\cdot}85 \times 10^{-12}$ g. of radium per scale division per hr. This value is very similar to that of the previous electroscopes employed. As a further check on the standardization, a repeat experiment was made on a basalt from Colorado, whose radium content had previously been twice measured, and a practically identical value was obtained.

The locality of origin and the radium contents of the available specimens are given in the following table :

Specimen.	Latitude.	Longitude.	Depth in metres.	Radium content 10^{-12} g. per g.
Basalt near Tillanchong (R.I.M.S. "Investigator")	8° 32′ N.	94° 10′ E.	2270	0·43
Augite-basalt, St. 133, 8	1° 26′ S.	66° 34′ E.	3385	0·46
Variolitic augite-basalt, St. 133, 12	,,	,,	,,	0·49
Hornblende augite-basalt, St. 133, 15	,,	,,	,,	0·49
Basalt, St. 166, 6	6° 55′ N.	67° 11′ E.	4793–4850	0·46
Mean value	—	—	—	0·466

The chief interest in the values obtained centres in their great uniformity and their low value. The freshness of the Tillanchong basalt, combined with the fact that it is probably of recent origin, indicates that this low radio-activity did not originate through a possible abstraction by the sea-water. Jeffreys (2) commented on a similar uniformity in the results for the Hawaiian basalts. It is noteworthy also that the basalt from near Tillanchong in the Nicobar Islands is at a considerable distance from the specimens from the neighbourhood of the Carlsberg Ridge, yet its radio-activity is practically the same. This fact, taken in conjunction with their low radium content, mean value about $0{\cdot}47 \times 10^{-12}$, compared with $0{\cdot}77 \times 10^{-12}$ for the Deccan basalts and 0·75 for all plateau basalts,

suggests that possibly we may be dealing with the parent basaltic strata from which the granites and surface basalts are derived. It is interesting to point out that these radio-active determinations support the idea put forward by Dr. Wiseman that the Carlsberg Ridge basalts are chemically quite distinct from the Deccan traps, and therefore cannot be their sunken representatives.

I have consulted Dr. Jeffreys as to the probable composition of the floor of the Western Indian Ocean, and he informs me that little is known either from seismological or gravitational data. It is usually considered, however, that whereas the floor of the Atlantic may be composed of more acid materials than basalt, the Pacific is probably floored with basalt, and in the absence of definite contrary evidence, we might assume that the Western Indian Ocean is similarly floored.

In any case the results fully confirm the view that the deeper the probable origin (*i. e.* the place where the rock solidified) of a rock, the less its radio-activity. It might be noted that the values for these basalts lie between the previous values obtained for surface basalts and eclogites, the latter being presumably of deeper origin.

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Trinity College,
Dublin;
January, 1937.

DESCRIPTION OF PLATE.

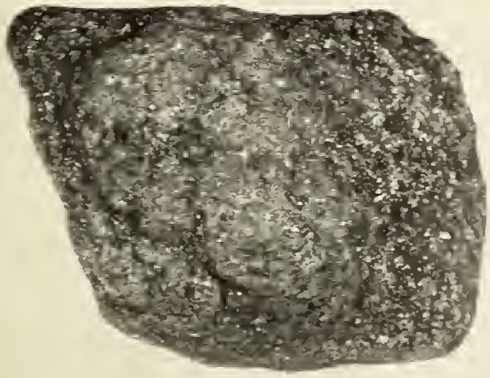
Fig. 1.—This specimen has a distinctly rounded appearance due to the peripheral coating of manganese nodule material. × 1 (St. 133, 8).

Fig. 2.—The exterior features of the hornblende-augite-dolerite are distinctly angular, and the peripheral black coating is of negligible thickness. × 2 (St. 133, 15).

Fig. 3.—This photograph of a sectioned specimen shows the junction between the interior basalt and the exterior black coating. The junction is sharp and the insoluble material occurs in a roughly radial direction. × 7 (St. 133, 8).

Fig. 4.—When the exterior manganese zone of a rounded specimen is removed an angular basaltic fragment is left behind. × 1 (St. 133, 8).

Fig. 5.—This section of a rounded specimen shows the exterior manganese material surrounding an angular fragment of basalt. The lighter material represents fragments of the insoluble material arranged in a radial direction. × 1 (St. 133, 8).



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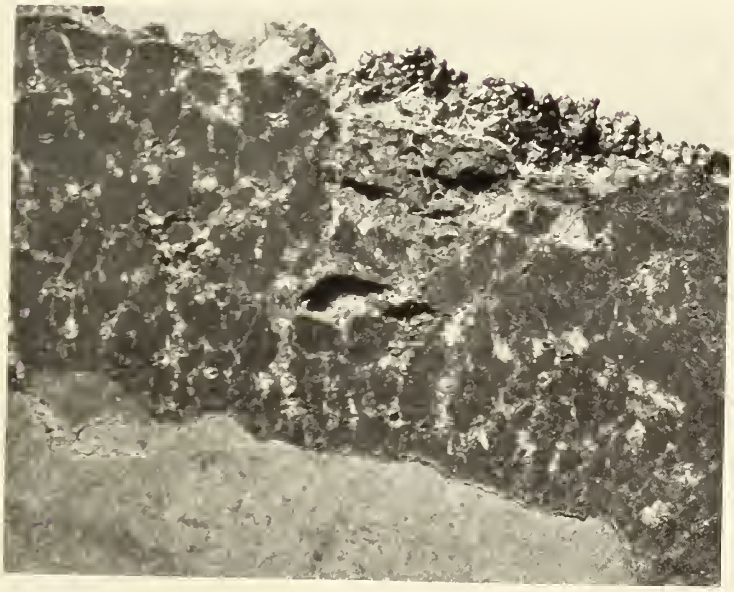

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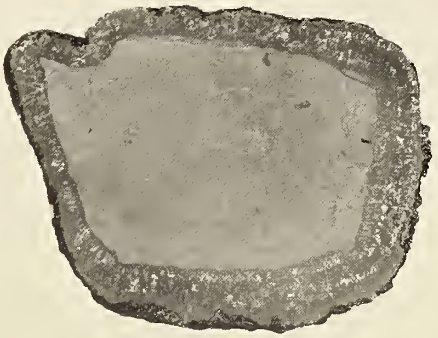

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THE MARINE DEPOSITS OF THE ARABIAN SEA

AN INVESTIGATION INTO THEIR DISTRIBUTION AND BIOLOGY

BY

H. G. STUBBINGS, M.A., Ph.D.(Cantab.), B.Sc.(Lond.)

WITH FOUR PLATES, FOUR CHARTS AND FIVE TEXT-FIGURES.

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CONTENTS

I. INTRODUCTION.

Historical.

Our knowledge of the deposits of the Indian Ocean is due almost entirely to the work of Sir John Murray, the founder of this branch of oceanographical investigation, whose methods have long influenced subsequent investigators in this field.

The first charts to show the distribution of deposits in the Indian Ocean were those prepared by Murray (1889), and Murray and Renard (1891). These incorporated all the data then available from many sources. Compared with more recent charts these early attempts to portray the nature of the bottom are extremely speculative.

The next chart of the deposits in the Indian Ocean is that prepared by Murray and Philippi (1908), incorporating the results of their investigation of the materials collected by the Deutsche Tiefsee-Expedition and of other available material collected by survey and cable ships. As a result of the "Sealark" Expedition (1905), a further report was prepared by Murray (1909), giving lists of all expeditions and vessels that had obtained physical oceanographical data in the Indian Ocean. In it is summarized our knowledge of the depths and deposits of the Indian Ocean up to that time.

Subsequent to this paper, two reports have appeared on the deposits of the Bay of Bengal and Andaman Sea (Sewell, 1925) and the Laccadive Sea (Sewell, 1935*a*). During the world cruise of the "Dana" in 1928–30 a line of echo-soundings was run from Colombo to the Seychelles, crossing a ridge to which Schmidt (1932) gave the name "Carlsberg Ridge", and which we now know to run from near Socotra in a south-easterly direction to near the Chagos Archipelago and then west of south as far as the Island of Rodriguez.

Apart from these three contributions no large advances in our knowledge of the topography and deposits of the Indian Ocean have been made since the "Sealark" report; the distribution of the several deposits in the north-western area was known in broad outline only, and the topography was extremely problematical. In both respects considerable advances have been made by the work of the "John Murray Expedition", and the topography is now known in some detail. In the present report the areas of the different deposits, as given by Murray, are, with slight alterations, confirmed. The degree of agreement between the new chart and that of 1909 is a striking tribute to the skill and insight of the late Sir John Murray in assessing the nature and value of the small and often insufficient samples of deposits at his disposal.

Collecting Gear.

The types of apparatus used for the collection of bottom samples are given in the description of the scientific equipment of the Expedition (Sewell, 1935*b*, p. 10). The most important are the following:

(i) *Driver sounding tube.*—This was of the standard pattern, and is fully described in 'Discovery Reports', I, p. 211 (Kemp *et al.*, 1929), under the name of "Ekman-Nansen Sounding Rod".

(ii) *Baillie sounding rod.*—This also was of the standard pattern, and is described in the above report (p. 210).

(iii) "*Bigelow*" *sounding rod.*—This was especially made for the Expedition. A description is given by Sewell (1935*b*, p. 10). Cores up to 5 feet long were obtained with this apparatus.

(iv) *Priestman grab.*—This grab was designed to cover an area of 0·5 sq. m. and was of a modified "Petersen" type. The chief modification is the provision of two wire closing ropes on the outside of the grab instead of the usual single chain working internally. By this arrangement the contents of the grab are not disturbed by the closure of the grab, but are received on board in the natural state.

MATERIALS.

185 deposit-samples were collected from 131 stations in the north-west area of the Indian Ocean by various forms of apparatus. The following summary (Table I) shows the material available for investigation and the means whereby it was obtained :

TABLE I.

Apparatus.	Number of samples.	Complete samples.	Mud samples.	Sifted samples.	Debris samples.
Bigelow tube	51	51	..	..	..
Priestman grab	42	28	6	7	1
Driver tube	7	7	..	..	..
Snapper lead	4	..	2	..	2
Baillie rod	3	3	..	..	..
Agassiz trawl	31	7	1	20	3
Otter trawl	8	1	1	1	5
Monegasque trawl	7	3	1	2	1
Triangular dredge	21	14	1	5	1
Rectangular dredge	6	..	1	1	4
Conical dredge	2	..	..	2	..
Miscellaneous	3	..	2	1	..
	185	114	15	39	17

In the above table " complete samples " are those in which a sample of mud and also a sample of the coarser material, sifted out from a large bulk of mud, is preserved. In the case of Bigelow cores, the column indicates the number of these only. " Mud samples " are intact (unsifted) material preserved in spirit. " Sifted samples " are samples of the coarse material separated from the mud. These were largely used to ascertain the relative proportions of the different organic constituents of the sediments. " Debris " samples are small amounts of mud removed from jars of specimens. These are of little value except for a few additional records of Foraminifera and other remains, and are only listed in the above table where they are the chief or only source of information for particular stations.

The depth distribution of the samples is as follows :

m.	Number of stations.	m.	Number of stations.
0–100	19	2000–3000	7
100–500	42	3000–4000	9
500–1000	19	4000–5000	8
1000–2000	26	Over 5000	1

Total stations, 131.

CLASSIFICATION.

The classification of the sediments used is as follows, the numbers indicating the number of stations at which each type was found ;

		Number of stations.
1. Grey mud and clay		12
2. Green and brown muds		50
3. Coarse deposits:		
(*a*) Sand	9	
(*b*) Rock	3	16
(*c*) Conglomerate	4	
4. Globigerina ooze		21
5. Pteropod ooze		8
6. Red clay		3
7. Coral deposits:		
(*a*) Mud	12	20
(*b*) Sand	8	
8. Doubtful (Sta. 115)		1
Total		131

The term "terrigenous deposits" has thus been avoided. It was used by Murray to include :

1. Shallow-water and littoral sands, gravels and muds.
2. The following deep-sea deposits :
   - Blue mud.
   - Red mud.
   - Green mud.
   - Volcanic mud.
   - Coral mud.

In the present work, "coral mud" and other coral reef deposits are regarded as distinct from true terrigenous deposits, as they are largely of organic origin. Furthermore, it seems likely that red clay will prove to be of similar origin to the deposits of the Continental margins, *i. e.* largely of terrestrial origin. As Murray considered red clay to be of pelagic or volcanic origin, I prefer not to use the term "terrigenous deposits" until the status of red clay is finally settled. The names of the various deposits grouped by Murray under this head are retained.

The positions of the samples examined are shown on Chart I. Where the stations occur very close together, as in the Maldives and off Ras al Hadd, several are frequently indicated by a single symbol. The following symbols have been used :

● Indicates a sample obtained by Bigelow tube, Driver tube or Baillie rod.

▲ Indicates a Priestman grab sample.

■ Indicates a sample obtained with a trawl or dredge.

✕ Indicates a debris sample where this alone represents a station.

The abbreviations used to denote the character of the deposit in some of the tables are those given in the "Station List" (Sewell, 1935*b*, p. 15) with the addition of the following two :

cs. Coarse.

gv. Gravel.

Methods.

Previous authors have concentrated on the description of marine deposits largely from the mineralogical and chemical standpoint. Little attention has been given to the biological remains present in the sediments, except by Murray and Renard (1891), or to the relationship between the sediments and the fauna. In the present report an attempt has been made to remedy this omission.

In examining the materials, the method employed was to shake a sample up with water and sift it through a fine linen sieve with meshes approximately 160μ in diameter. In this way it was possible to separate the larger mineral particles and animal remains from the mud. Remains as small as single and broken chambers of *Globigerina* could be separated by this means. Very coherent muds and clays were first boiled in water, and potash added if necessary to break down the lumps. The coarse fraction remaining on the sieve was washed on to a filter-paper, dried and weighed. The fine mud, passing with the water through the sieve, was likewise filtered off, dried and weighed. Both weights were then expressed as a percentage of the whole.

The relative amounts of the different remains were obtained by taking a representative sample of the sifted material, sorting this into the several groups and determining the percentage by weight of each.

The animal components have not all been identified. The Pteropoda and the majority of the Foraminifera have been determined specifically. Corals, some few Polyzoa and various of the more obvious Mollusca have been referred to their genera. In most instances it was possible only to separate the remains into Lamellibranchiata, Gasteropoda or Scaphopoda owing to the fragmentary condition of the shells. Other remains have merely been classed in their phylum or order, except for a few rare instances where generic or specific names are given.

Acknowledgments.

The thanks of the author are due to the following : to Prof. J. Stanley Gardiner and Lt.-Col. R. B. Seymour Sewell for suggesting the investigation, and for much advice and guidance during its execution ; to Mr. J. R. Norman, British Museum, for identification of fish teeth ; to Dr. J. D. H. Wiseman, British Museum, for advice and identifications of rocks ; to Dr. E. F. Thompson, for permission to make use of unpublished hydrographical data on the area ; to Dr. S. Chaffers for the identification of the diatoms at Stas. 55 and 56 ; and finally to Messrs. D. J. Buck and E. W. Mynott for the preparation respectively of the photographs for the plates and the originals of the text-figures and charts.

II. DESCRIPTION OF THE DEPOSIT-SAMPLES.

In this section the following expressions have been used :

(*a*) Coarse material or sample :

This indicates a sample in which the fine or mud portion has been washed out and is not available for investigation.

(*b*) Incomplete sample :

A sample, usually obtained with a net, from which an unknown amount of the mud has been washed out during its passage to the surface.

(*c*) Debris :

This term is used in the same sense as in Table I (p. 34).

In the tables of this section the following expressions need clarifying :

(*a*) " Frequency " :

This indicates a relationship between the number of specimens or fragments of the different components, and thus bears no relationship to the percentage figures given in columns 3 and 4, which are calculated on weights. The following symbols are used : R, rare ; F, frequent ; C, common ; VC, very common ; A, abundant.

(*b*) " Other remains " :

Unless otherwise stated, under this term are included (1) carbonaceous matter and mineral grains ; (2) unidentifiable calcareous material ; and occasionally (3) animal fragments too rare for estimation separately. These latter are sometimes estimated, where all together form a sufficient quantity, as " Other animals ".

The classification and nomenclature of the Foraminifera adopted throughout is that given by Cushman (1928, 2nd ed., 1933), and used by Thalmann (1932) to rename the species illustrated in Brady's report on the Foraminifera of the " Challenger " Expedition.

Station 5 : Red Sea ; depth 938 metres ; Driver tube sample ; brownish-yellow calcareous mud (red-brown when wet) with abundant pelagic Foraminifera and some Pteropod fragments ; mud 85·9% ; organic remains 14·1%.

Pelagic remains :—

Foraminifera.

Globigerina bulloides	*Globigerinoides sacculifera.*
Gl. dubia.	*Globigerinella æquilateralis.*
Globigerinoides rubra.	*Orbulina universa.*

Pteropoda.

Peraclis bispinosa.	*Creseis virgula.*
Limacina bulimoides.	*Hyalocylis striata.*
L. inflata.	*Clio pyramidata.*
L. trochiformis.	*Cavolinia longirostris.*
Creseis acicula.	*Atlanta* sp.

No specimens of *Pulleniatina obliquiloculata* or of *Globorotalia* spp. occur at this or the following station.

Benthic remains :—

One Foraminiferan, *Verneulina propinqua*, only, and a few otoliths are present.

Station 6 : Red Sea ; depth 1167 metres ; coarse Salpa dredge sample ; soft calcareous rock bottom with embedded species of Pteropoda.

Pelagic remains :—

Foraminifera.

Globigerina bulloides.

Pteropoda.

Limacina inflata. *Diacria quadridentata.*
Creseis acicula. *Cavolinia longirostris.*
Cr. virgula. *Atlanta* sp.
Hyalocylis striata.

In addition a few Gasteropoda and small translucent Lamellibranch valves are present in the matrix. *Globigerina bulloides* and *Limacina inflata* occur in considerable numbers. Other organisms are rather rare.

Station 7 : Red Sea ; depth 260 metres ; coarse conical dredge sample ; terrigenous sand with numerous Pteropod shells.

Chief components.	Frequency.	% coarse material.
Foraminifera	C	2·3
Corals	R	0·9
Echinodermata	R	2·0
Crustacea	F	3·4
Lamellibranchiata	R	4·2
Gasteropoda	F	11·0
Pteropoda	VC	16·9
Scaphopoda	R	0·4
Pisces	F	5·5
Other remains	VC	53·4
		100·0

Pelagic remains :—

Foraminifera.

Globigerina bulloides. *Globorotalia menardii.*
Pulleniatina obliquiloculata.

Pteropoda.

Limacina inflata. *Diacria quadridentata.*
Creseis virgula. *Cavolinia longirostris.*
Hyalocylis striata. *Atlanta* sp.
Clio pyramidata.

Benthic remains :—

Foraminifera.

Textularia pseudocarinata. *Pyrgo sarsi.*
T. sagittula var. *fistulosa.* *Eponides haidingeri.*
Spiroloculina depressa. *Rotalia papillosa.*
Sp. grateloupi. *Miniacina miniacea.*

Other remains : Cirriped valves.

The majority of the Foraminifera are worn and broken Rotaliidæ and Miliolidæ. Other species are rare. The abundance of Cirriped valves is remarkable, terga, scuta and

carinæ of at least two species of *Scalpellum* and valves and compartments of *Balanus* spp. being present. Small solitary corals are common. Among the shells are a few larval *Triforis* (="*Limacina turritelloides*" of Boas).

Station 9: Red Sea: depth 245 metres; no deposit sample was retained. The following Foraminifera occurred among debris:

Homotrema rubrum.	*Sporadotrema mesentericum.*
Sporadotrema cylindricum.	*Miniacina miniacea.*

Station 10: Red Sea; depth 55 metres; no deposit sample was retained. The following Foraminifera occurred among debris:

Sigmoidella elegantissima.	*Planorbulinella larvata.*
Operculina granulosa.	*Carpenteria utricularis.*
Heterostegina depressa.	*Homotrema rubrum.*
H. operculinoides.	*Sporadotrema cylindricum.*
Sorites marginalis.	*Sp. mesentericum.*
Amphistegina radiata.	*Miniacina miniacea.*

Station 14: Gulf of Aden; depth 1764 metres; Driver tube sample; green-brown mud with fine Pteropod fragments and Foraminifera; mud 88·7%: organic remains 11·3%.

Pelagic remains:—

Foraminifera.

Globigerina bulloides.	*Orbulina universa.*
Gl. dubia.	*Globorotalia menardii.*
Globigerinella æquilateralis.	

Pteropoda.

Limacina inflata.	*Creseis* sp.
L. trochiformis.	

One benthic Foraminiferan, *Spiroloculina depressa*, only was present.

Animal remains in this deposit are very small and rare. There is considerable organic matter and few mineral particles.

Station 15: Gulf of Aden; depth 1053 metres; Bigelow sample; green-brown terrigenous mud with some pelagic Foraminifera; mud 83·2%; organic remains 16·8%.

Pelagic remains:—

Foraminifera.

Globigerina bulloides.	*Globigerinoides sacculifera.*
Gl. dubia.	*Globigerinella æquilateralis.*
Globigerinoides rubra.	*Globorotalia menardii.*

Benthic remains:—

Foraminifera.

Quinqueloculina sp.	*Uvigerina pygmæa.*
Robulus sp.	*Discorbis* sp.

Other remains are very rare, and are represented by a few fragments of Pteropoda, *Atlanta* spp., shells and Echinoderm spines.

Station between 15 and 16: Gulf of Aden; depth ?; fragmentary Driver tube sample; green mud with Foraminifera; mud 90·4%; organic remains 9·6%.

Pelagic remains :—

Foraminifera.

Globigerina bulloides.
Gl. dubia.
Globigerinoides conglobata.
Gl. rubra.
Gl. sacculifera.
Globigerinella æquilateralis.
Orbulina universa.
Pulleniatina obliquiloculata.
Globorotalia canariensis.
Gl. menardii.

Benthic remains :—

Foraminifera.

Dentalina communis.
Bulimina elegans.
B. pupoides.
B. pyrula.
B. subornata.
Uvigerina bifurcata.
Uvigerina schwageri.
Cancris auriculus.
Anomalina balthica.
Planulina wuellerstorfi.
Laticarinina pauperata.

The organic components are almost entirely Foraminifera. A very few remains of shells, Pteropoda and Echinoderm spines are present.

Station 16: Gulf of Aden; depth 186 metres; Driver tube sample; brown-green calcareous mud with some Foraminifera and Pteropod fragments; mud 88·4%; organic remains 11·6%.

Pelagic remains :—

Foraminifera.

Globigerina bulloides.
Gl. dubia.
Globigerinoides rubra.
Orbulina universa.
Pulleniatina obliquiloculata.
Globorotalia menardii.

Pteropoda.

Cavolonia sp. (fragment).

Benthic remains :—

Foraminifera.

Clavulina sp.
Robulus sp.
Planulina ammonoides.
Bulimina aculeata.
Bulimina elongata.
B. ovata.
Uvigerina pygmæa.

The deposit appears to contain much organic matter and few mineral grains. Siliceous remains are absent and fæcal pellets abundant.

Station 17: Gulf of Aden; depth 854 metres; Bigelow sample; fine brown sandy mud; mud 94·2%; organic remains 5·8%.

Pelagic remains :—

Foraminifera.

Globigerina bulloides.
Gl. dubia.
Globigerinella æquilateralis
Globorotalia menardii.

Pteropoda.

Limacina inflata. — *Clio pyramidata.*
Creseis acicula. — *Diacria quadridentata.*
Cr. virgula. — *Cavolinia* sp.
Hyalocylis striata.

The deposit contains much fine quartz sand. Remains of benthic organisms and siliceous organisms are absent.

Station 18 : Gulf of Aden ; depth 1375 metres ; Driver tube sample ; brown-green calcareous mud ; mud 84·7% ; organic remains 15·3%.

Pelagic remains :—

Foraminifera.

Globigerina bulloides. — *Pulleniatina obliquiloculata.*
Globigetinoides rubra. — *Globorotalia menardii.*
Orbulina universa.

Much organic matter is present. Siliceous remains and benthic organisms are unrepresented. Fæcal pellets are very abundant (see Pl. I, fig. 4).

Station 20 : Gulf of Aden ; depth 1132 metres ; Bigelow sample ; green calcareous mud with numerous Foraminifera and some Pteropoda ; mud 80·6% ; organic remains 19·4%.

Pelagic remains :—

Foraminifera.

Globigerina bulloides. — *Orbulina universa.*
Globigerinoides conglobata. — *Pulleniatina obliquiloculata.*
Gl. rubra. — *Globorotalia menardii.*

Pteropoda.

Creseis virgula. — *Clio pyramidata.*

Benthic remains :—

Foraminifera.

Pyrgo depressa. — *Uvigerina* sp.
Nodosaria consobrina var. *emaciata.* — *Chilostomella ovoidea.*
Lagena sp.

Some fæcal pellets and a few rare Gasteropod fragments are present. There is considerable organic matter present, but no siliceous organisms occur (see Pl. I, fig. 3).

Station 21 : Gulf of Aden ; depth 1518 metres ; Bigelow sample ; green calcareous mud ; mud 82·8% ; organic remains 17·2%.

Pelagic remains :—

Foraminifera.

Globigerina bulloides. — *Pulleniatina obliquiloculata.*
Gl. dubia. — *Globorotalia menardii.*
Globigerinoides rubra.

Benthic remains :—

Foraminifera.

Quinqueloculina sp. *Bulimina ovata.*

Foraminifera and a few otoliths are practically the only remains present in this deposit. Much organic matter is present. A very few Radiolarian fragments are the only siliceous representatives.

Station 22 : Central Arabian Sea ; depth 3556 metres ; Bigelow sample ; white Globigerina ooze ; mud 87·4% ; organic remains 12·6%.

Pelagic remains :—

Foraminifera.

Globigerina bulloides. *Pulleniatina obliquiloculata.*
Gl. dubia. *Globorotalia menardii.*
Globigerinoides sacculifera.

This is an almost pure Globigerina ooze, and no red clay residue is left on dissolving out the calcium carbonate. The Foraminifera are almost all fragmentary, and no benthic forms are present. Siliceous remains are plentiful and include *Lithocircus* and other Radiolaria, Poriferan spicules, and diatoms, including a few specimens of *Coscinodiscus* sp. Poriferan fragments are quite common.

Station 24 : Gulf of Aden ; depth 73–200 metres ; incomplete Conical dredge sample ; yellow sand and calcareous conglomerate. The sand is 86·4% calcareous, the remainder being mainly quartz particles.

Pelagic remains :—

Foraminifera.

Globigerina bulloides. *Globorotalia menardii.*

Pteropoda.

Limacina helicina. *Creseis acicula.*

Benthic remains :—

Foraminifera.

Textularia carinata. *Uvigerina pygmæa.*
Triloculina sp. *Rotalia* sp.
Robulus sp. *Miniacina miniacea.*
Vaginulina ? tricarinella.

In addition the following also occur : Poriferan spicules, Alcyonarian spicules, *Cellaria*, Crustacean skeletal fragments, Echinoderm spines, Gasteropod and Lamellibranch fragments. The majority of these remains are rare. The conglomerate collected with the sand consists of clusters of dead *Balani* (? *B. amphitrite*) overgrown with Lithothamnia and Serpulid tubes, pieces of calcareous rock composed of shell fragments in a white calcareous matrix, and pieces of shell and other rubble overgrown by Lithothamnia.

Station 26 : Gulf of Aden ; depth 2312 metres ; Bigelow and incomplete Agassiz trawl samples ; very fine, light fawn-grey calcareous mud with few organic particles ; organic remains *circa* 1–2%.

Chief components.	Frequency.	% coarse material.
Foraminifera	C	10·6
Polychæta	R	0·5
Echinodermata	R	1·2
Lamellibranchiata	R	1·1
Gasteropoda	R	0·5
Pisces	R	1·2
Unidentified	C	84·9
		100·0

Pelagic remains :—

Foraminifera.

Globigerina bulloides. *Globigerinoides sacculifera.*
Gl. dubia. *Globorotalia menardii.*

Pteropoda.

Diacria quadridentata. *Atlanta* sp.
Cavolinia longirostris.

Benthic remains :—

Foraminifera.

Rhabdammina abyssorum. *Reophax pilulifer.*
Rh. discreta. *Hormosina carpenteri.*
Rh. linearis. *H. globulifera.*
Crithionina pisum. *Haplophragmoides subglobosum.*
Cr. pisum var. *hispida.* *Clavulina communis* var. *nudulosa.*
Marsipella cylindrica. *Pyrgo depressa.*
Storthosphæra albida. *P. murrhina.*
Pilulina jeffreysi. *Lenticulina reniformis.*
Hyperammina elongata. *Bulimina pyrula.*
H. friabilis. *Rotalia beccarii.*
H. lævigata. *Epistomina elegans.*
Saccorhiza ramosa. *Planulina wuellerstorfi.*

Pteropoda.

Diacria quadridentata. *Atlanta* sp.
Cavolinia longirostris.

The coarse material consists almost entirely of small aggregates of Foraminiferal and other fragments, apparently portions of worm-tubes. The Foraminifera are almost all benthic forms ; apart from these, organic remains are rare. In the foregoing table most of the Polychæte tubes are composed of *Globigerina* spp. and *Globorotalia* spp., and so are counted in with the Foraminifera. Only the non-foraminiferal tubes are classified separately ; these are not common. A few Poriferan spicules were the only siliceous remains observed.

Station 27 : Gulf of Aden ; depth 37 metres ; Otter trawl debris ; coarse shell, coral and quartz sand.

Benthic remains :—

Foraminifera.

Textularia agglutinans.
T. gramen.
Spiroloculina grateloupi.
Spirophthalmidium acutimargo.
Elphidium crispum.
El. macellum.
Ozawaia tongaensis.
Operculina granulosa.
Alveolinella boscii.
Bolivina simpsoni.
Chrysalidinella dimorpha.
Rotalia papillosa.
Amphistegina radiata.
Gypsina vesicularis.
Miniacina miniacea.

The rest of the material consists of Echinoderm spines, fragments of Polyzoa, Alcyonarian spicules, coral, *Halimeda* and molluscan fragments. A considerable amount of the fine material seems to be of molluscan origin. Pelagic remains are very rare and are represented by a few *Globigerina* fragments only. The sand contains about 6·2% of quartz, the rest being calcareous material, mainly of organic origin.

Station 28 : Gulf of Aden ; depth 201 metres ; Priestman grab samples ; green sandy mud with numerous Pteropod and shell fragments ; mud 25·3% ; organic remains 74·7%.

Chief components.	Frequency.	% coarse material.	% deposit.
Foraminifera	R	0·6	0·5
Polychæta	R	0·5	0·4
Echinodermata	A	22·8	16·9
Crustacea	R	1·2	0·9
Lamellibranchiata	VC	22·6	16·8
Gasteropoda	VC	23·6	17·5
Pteropoda	VC	19·1	14·2
Scaphopoda	F	2·7	2·4
Other remains	F	6·9	5·1
		100·0	74·7

Pelagic remains :—

Foraminifera.

Globigerina bulloides.
Gl. dubia.
Globorotalia menardii.
Tretomphalus bulloides.

Pteropoda.

Limacina bulimoides.
L. inflata.
Creseis acicula.
Cr. virgula.
Hyalocylis striata.
Clio pyramidata.
Diacria quadridentata.
Cavolinia longirostris.
Atlanta sp.

Benthic remains :—

Foraminifera.

Rhizammina algæformis.
Reophax sp.
Textularia conica.
T. pseudocarinata.
T. rhomboidalis.
Robulus denticuliferus.

Nodosaria vertebralis.
Bolivina amygdalæformis.
Uvigerina pygmæa.
Rotalia sp.
Ehrenbergina pacifica.
Cibicides lobatulus.
C. refulgens.

Mollusca.

Ianthina sp.
Solarium sp.
? *Venus torresiana.*

Echinoderm remains are represented by very numerous Spatangoid spines, fragments of Echinoids and Ophiuroid "vertebræ". Fish otoliths and vertebræ and *Balanus* fragments occur. Small fæcal pellets are common. Siliceous organisms are represented by long, slender sponge spicules.

Station 29 : Gulf of Aden ; depth 2072 metres ; Bigelow sample ; light brown highly calcareous, friable mud ; mud 65·5% ; organic remains 34·5%.

Pelagic remains :—

Foraminifera.

Globigerina bulloides.
Gl. dubia.
Globigerinoides rubra.
Gl. sacculifera.
Globigerinella æquilateralis.
Hastigerina pelagica.
Orbulina universa.
Globorotalia menardii.

Pteropoda.

Creseis acicula.

Benthic remains :—

Foraminifera.

Triloculina sp.
Pyrgo murrhina.
Bulimina ovata.

Molluscan remains include small shells of Gasteropoda and Scaphopoda. Fæcal pellets are common. Poriferan spicules are fairly frequent and a few rare Radiolaria occur.

Station 32 : Gulf of Aden ; depth 1178 metres ; Bigelow sample ; green, calcareous mud with Foraminifera ; mud 84·1% ; organic remains 15·9%.

Pelagic remains :—

Foraminifera.

Globigerina bulloides.
Gl. dubia.
Globigerinoides rubra.
Gl. sacculifera.
Globigerinella æquilateralis.
Orbulina universa.
Pulleniatina obliquiloculata.
Globorotalia menardii.

Pteropoda.

Cavolinia sp.

Benthic remains :—

Foraminifera.

Bulimina affinis.
Uvigerina pygmæa.
Planulina ammonoides.

Fæcal pellets, Radiolaria and sponge spicules are all rare.

Station 33: Gulf of Aden; depth 1295 metres; Bigelow and incomplete Agassiz trawl sample; green, calcareous, coprolitic mud.

Pelagic remains:—

Foraminifera.

Globigerina bulloides.
Gl. dubia.
Globigerinoides rubra.
Gl. sacculifera.
Orbulina universa.
Pulleniatina obliquiloculata.
Globorotalia menardii.

The only benthic Foraminiferan identified was *Chilostomella ovoidea.* The deposit consists largely of fæcal pellets. Pelagic Foraminifera, fish scales and shell fragments are fairly common. Broken valves of *Amussium* sp. and shells of *Pleurotoma* were identified.

Station 34: Gulf of Aden; depth 1032 metres; Bigelow and Agassiz trawl samples; brown calcareous mud with fæcal pellets and Foraminifera; mud 79·9%; organic remains 20·1%.

Pelagic remains:—

Foraminifera.

Globigerina bulloides.
Gl. dubia.
Globigerinoides rubra.
Globigerinella æquilateralis.
Hastigerina pelagica.
Orbulina universa.
Pulleniatina obliquiloculata.
Sphaeroidinella dehiscens.
Globorotalia canariensis.
Gl. menardii.

Pteropoda.

Limacina inflata.
Creseis virgula.
Hyalocylis striata.

Benthic remains:—

Foraminifera.

Spiroplectammina milletti.
Gaudryina pseudofiliformis.
Clavulina communis.
Sigmoilina schlumbergeri.
Robulus calcar.
Lenticulina rotulata.
Nodosaria scalaris.
Bulimina aculeata.
B. pupoides.
Uvigerina bifurcata.
U. schwageri.
Angulogerina carinata var. *bradyana.*
Rotalia beccarii.
Cancris auriculus.
Ehrenbergina pacifica.
Chilostomella ovoidea.
Planulina ariminensis.
Pl. wuellerstorfi.

A few broken Gasteropod and Dentaliid shells are the only large fragments present. The other remains are of the size of *Globorotalia menardii* or smaller. Small *Globigerina* are very common, followed by *Globorotalia* and fæcal pellets in that order. *Uvigerina* is common, but the other benthic Foraminifera are rare numerically, usually being represented by one or two specimens only.

Station 35: Gulf of Aden; depth 441 metres; Bigelow sample; brown-green calcareous, friable mud; mud 68·6%; organic remains 31·4%.

Pelagic remains :—

Foraminifera.

Globigerina bulloides. *Hastigerina pelagica.*
Gl. dubia. *Orbulina universa.*
Globigerinoides conglobata. *Pulleniatina obliquiloculata.*
Gl. rubra. *Globorotalia menardii.*

Pteropoda.

Limacina inflata. *Diacria quadridentata.*
Creseis acicula. *Cavolinia tridentata.*
Cr. virgula. *Atlanta* sp.

The benthic remains include only two species of Foraminifera, *Saracenaria italica* and *Bulimina* sp. Lamellibranch valves, *Cadulus* sp. and fæcal pellets also occur. The latter are common. Siliceous remains are absent.

Station 38 : Gulf of Aden ; depth 2458 metres ; Bigelow sample ; light fawn-grey calcareous mud with few macroscopic remains ; mud 95·1% ; organic remains 4·9%.

Pelagic remains :—

Foraminifera.

Globigerina bulloides. *Pulleniatina obliquiloculata.*
Gl. dubia. *Globorotalia menardii.*
Globigerinoides rubra.

Benthic remains :—

Foraminifera.

Clavulina ? communis. *Bulimina aculeata.*
Pyrgo murrhina. *Planulina wuellerstorfi.*

No other calcareous remains are present. Siliceous remains include Poriferan spicule fragments, diatoms (*Coscinodiscus*) and a very few Radiolaria.

Station 39 : Gulf of Aden ; depth 2156 metres ; Bigelow sample ; fawn-grey calcareous mud ; mud 96·3% ; organic remains 3·7%.

Pelagic remains :—

Foraminifera.

Globigerina dubia. *Pulleniatina obliquiloculata.*
Globigerinella æquilateralis. *Globorotalia menardii.*
Orbulina universa.

Benthic remains :—

Foraminifera.

Pyrgo murrhina. *Gyroidina soldani.*
Nonion umbilicatulum. *Planulina wuellerstorfi.*

Poriferan spicules and Radiolaria are rare, but *Coscinodiscus* is fairly frequent.

Station 42 : South Arabian Coast ; depth 1415 metres ; debris and large fragments ; no complete sample of the deposit is available. The debris contained the following Foraminifera :

Globigerina sp. *Rhizammina algæformis.*
Globorotalia menardii.

Station 43 : South Arabian Coast ; depth 95 metres ; no sample except debris containing :

Foraminifera.

Carpenteria monticularis.
C. proteiformis.
C. utricularis.
Sporadotrema cylindricum.
Sp. mesentericum.
Miniacina miniacea.

Station 45 : South Arabian Coast ; depth 48 metres ; coarse dredge and debris samples ; calcareous conglomerate and *Lithothamnion.*

Benthic remains :—

Foraminifera.

Textularia sp.
Quinqueloculina agglutinans.
Q. intricata.
Spiroloculina grateloupi.
Triloculina tricarinata.
T. trigonula.
Pyrgo anomala.
Carterina spiculotesta.
Nodosaria subscalaris.
Guttulina yabei.
Sigmoidella elegantissima.
Elphidium craticulatum.
El. crispum.
Operculina granulosa.
Heterostegina depressa.
Sorites marginalis.
Discorbis globularis var. *bradyi.*
Gyroidina soldani.
Eponides præcinctus.
Planopulvinulina dispansa.
Rotalia papillosa.
Amphistegina radiata.
Cibicides refulgens.
Planorbulinella larvata.
Gypsina globulus.
Sporadotrema cylindricum.
Sp. mesentericum.
Miniacina miniacea.

The material consists of large lumps of *Lithothamnion*-covered calcareous conglomerate. The usual encrusting organisms, such as Polyzoa, Polychæta and Foraminifera, are present. The coral *Pavona* occurs here. The following Polyzoa were identified : *Crisia* sp., *Hornera* sp., and *Cellepora* sp. Poriferan spicules were abundant, but Echinoderm and Alcyonarian spicules rare.

Station 50 : South Arabian Coast ; depth 1536–1939 metres ; dredge sample ; brown-green Foraminiferal mud ; mud 67·6% ; organic remains 32·4%.

Pelagic remains :—

Foraminifera.

Globigerina bulloides.
Gl. dubia.
Globigerinoides rubra.
Gl. sacculifera.
Orbulina universa.
Pulleniatina obliquiloculata.
Sphæroidinella dehiscens.
Globorotalia menardii.
Gl. canariensis.

Benthic remains :—

Foraminifera.

Rhabdammina abyssorum.
Crithionina pisum var. *hispida.*
Cyclammina sp.
Sigmoilina schlumbergeri.
Polymorphina sp.
Nonion umbilicatulum.
Bulimina aculeata.
Uvigerina brunnensis.
U. proboscidea.
Chilostomella ovoidea.
Planulina wuellerstorfi.

The deposit contains almost exclusively Foraminiferal tests, mainly of pelagic species. A few small fragments of Echinoderm spines are the only other remains recognizable. The mud appears to contain a considerable amount of organic matter.

Station 53 : South Arabian Coast ; depth 13·5 metres : coarse dredge sample only ; coarse calcareous sand.

Chief components.	Frequency.	% coarse material.
Foraminifera	R	1·3
Crustacea	F	2·1
Calcareous gravel	A	64·2
Other mineral gravel	A	32·4
		100·0

Benthic remains :—

Foraminifera.

Quinqueloculina rupertiana. *Operculina granulosa.*
Triloculina trigonula. *Heterostegina depressa.*
Elphidium craticulatum. *Amphistegina radiata.*
El. crispum.

Globigerina bulloides was the only pelagic species identified. The sand is mainly of organic origin, but much of the calcareous material is unidentifiable. Lumps of calcareous conglomerate and small stones encrusted with *Lithothamnion* and Serpulid tubes are common. Fragments of *Balanus amphitrite* and various Poriferan spicules, including some of *Hyalonema* type, are present.

Station 54 : South Arabian Coast ; depth 1046 metres ; Agassiz trawl sample ; stiff, green, clayey mud with few animal remains ; mud 82·1% ; organic remains 17·9%.

Pelagic remains :—

Foraminifera.

Globigerina bulloides. *Globigerina dubia.*

Benthic remains :—

Foraminifera.

Textularia conica. *Bulimina pyrula* var. *spinescens.*
Clavulina pacifica. *Virgulina subsquamosa.*
Robulus limbosus. *Bolivina beyrichi* var. *alata.*
Dentalina consobrina. *Uvigerina brunnensis.*
Nodosaria pyrula. *U. proboscidea.*
Frondicularia advena. *U. pygmæa.*
Lagena marginata. *Siphogenerina virgula.*
Bulimina ovata. *Sphæroidina bulloides.*
B. pyrula.

The mud is not homogeneous, but contains hard, brittle masses bored by Mollusca. These pieces are not very clayey, but are calcareous, and appear to be consolidated about the borings. Fæcal pellets occur to a small extent in the unconsolidated mud. No siliceous remains were found.

Station 55 : South Arabian Coast ; depth 794 metres ; Salpa dredge and Bigelow samples ; dark brown-green diatomaceous mud.

This is a slightly calcareous sandy mud with much organic matter and very numerous diatom frustules, of the species *Coscinodiscus oculis-iridis* var. *borealis* (Bail.), Cl. A small amount of coarse material was obtained, and this consists of worn Foraminifera, mainly benthic forms, and pieces of calcareous rock formed of shell and Foraminiferan material, cemented together. Some fish-scales are present (see Pl. I, figs. 5, 6).

Station 56 : South Arabian Coast ; depth 421 metres ; coarse and entire dredge samples ; fine green mud ; mud 94·8% ; organic remains 5·2%.

Chief components.	Frequency.	% coarse material.	% deposit.
Polychæta	C	8·6	0·4
Polyzoa	R	1·6	0·1
Echinodermata	R	1·8	0·1
Crustacea	F	2·6	0·1
Lamellibranchiata	C	9·4	0·5
Gasteropoda	F	7·3	0·4
Pteropoda	C	7·8	0·4
Pisces	VC	10·7	0·5
Other remains	A	50·2	2·7
		100·0	5·2

Pelagic remains :—

Foraminifera.

Globigerina bulloides.
Gl. dubia.
Globigerinoides sacculifera.
Globigerinella æquilateralis.
Orbulina universa.
Pulleniatina obliquiloculata.
Globorotalia menardii.

Pteropoda.

Creseis acicula.
Cr. virgula.
Hyalocylis striata.
Clio pyramidata.
Diacria quadridentata.
Cavolinia longirostris.
Atlanta sp.

Benthic remains :—

Foraminifera.

Operculina granulosa.
Bulimina pyrula.
B. subornata.
Virgulina squamosa.
Bolivina pygmæa.
Uvigerina tenuistriata.
Amphistegina radiata.

Sulphuretted hydrogen was present in this mud. Fish bones and scales are very abundant. Otoliths and sharks' teeth are present, but in fewer numbers. The same species of *Coscinodiscus*, *C. oculis iridis* var. *borealis*, is present at this station, but is less abundant than at the preceding.

Station 57 : South Arabian Coast ; depth 703 metres ; coarse dredge sample ; soft green mud ; mud 93·2% ; organic remains 6·8%.

Pelagic remains :—

Foraminifera.

Globigerina bulloides.	*Globorotalia canariensis.*
Gl. dubia.	*Gl. menardii.*
Orbulina universa.	

Pteropoda.

Creseis acicula.	*Cavolinia longirostris.*
Cr. virgula.	*Atlanta* sp.
Diacria quadridentata.	

Benthic remains :—

Foraminifera.

Nonionella sp.	*Uvigerina tenuistriata.*
Bulimina ovata.	? *Siphogenerina dimorpha.*
B. pyrula.	*Valvulineria allomorphinoides.*
Bolivina beyrichi.	*Cancris auriculus.*
B. pygmæa.	*Ehrenbergina pacifica.*
Uvigerina pygmæa.	

Some sulphuretted hydrogen was present in the mud, but less than at Sta. 56. There are no diatoms here, and animal remains are rare. The chief components are fish-bones, scales and otoliths. Rare Crustacean and Echinoderm remains occur. There is some limestone on the bottom.

Station 58 : South Arabian Coast ; depth 1189–1354 metres ; dredge sample ; calcareous rock and limestone.

The deposit here is recorded in the " Station List " as green mud, but no sample is preserved beyond the rock fragments. The calcareous rock is very soft and contains numerous shell-fragments and benthic Foraminifera. A few pieces show *Globigerina* spp., *Orbulina universa* and *Globorotalia menardii.* Rotaliidæ, Otoliths and Echinoderm remains are readily recognizable in this soft calcareous conglomerate.

Station 59 : South Arabian Coast ; depth 1948 metres ; Bigelow sample ; light brown calcareous mud ; mud 86·0% ; organic remains 14·0%.

Pelagic remains :—

Foraminifera.

Globigerina bulloides.	*Orbulina universa.*
Gl. dubia.	*Pulleniatina obliquiloculata.*
Globigerinoides rubra.	*Globorotalia menardii.*

Benthic remains :—

Foraminifera.

Clavulina communis.	*Laticarinina pauperata.*
Bulimina ovata.	

Foraminifera are the only organic calcareous remains present in this deposit. A few monaxon and triaxon sponge spicules were the only siliceous remains found. Organic matter is abundant.

Station 60 : Northern Arabian Sea ; depth 3054 metres ; small Bigelow sample ;

grey-brown, highly calcareous mud with a considerable number of intact Foraminifera; mud 82·3%; organic remains 17·7%.

Pelagic remains (see Pl. II, fig. 5):—

Foraminifera.

Globigerina bulloides.
Gl. dubia.
Globigerinoides conglobata.
Gl. rubra.
Globigerinoides sacculifera.
Orbulina universa.
Pulleniatina obliquiloculata.
Globorotalia menardii.

This deposit resembles a Globigerina ooze to some extent, but contains a considerable amount of material insoluble in hydrochloric acid and apparently of a clay nature. Unlike similar oozes bordering on Red clay, this material is not red-brown, like red clay, but is a dirty brownish-grey colour. The non-calcareous part of this deposit is thus probably intermediate in composition between red and grey clay.

Station 62: Northern Arabian Sea; depth 1893 metres; small Bigelow sample; grey calcareous, clayey deposit, impure Globigerina ooze; mud 87·5%; organic remains 12·5%.

Pelagic remains:—

Foraminifera.

Globigerina bulloides.
Gl. dubia.
Globigerinoides conglobata.
Gl. rubra.
Globigerinoides sacculifera.
Pulleniatina obliquiloculata.
Globorotalia menardii.

Benthic remains:—

Foraminifera.

Pyrgo serrata.
Bulimina aculeata.

This deposit is very similar to that from the preceding station, but there are fewer Foraminifera.

Station 63: Northern Arabian Sea; depth 1703 metres; small Bigelow sample; grey-green, calcareous, clayey deposit with very few Foraminifera; mud 94·4%; organic remains 5·6%.

Pelagic remains:—

Foraminifera.

Globigerina bulloides.
Globigerinoides rubra.
Globorotalia menardii.

This deposit is a pure grey clay. The only benthic Foraminiferan found was a species of *Bulimina.* There are no siliceous remains. The insoluble material is green-grey.

Station 64: Gulf of Oman; depth 448 metres; small Bigelow sample; grey clay; mud 94·9%; organic remains 5·1%.

There are exceedingly few animal remains in this deposit. The following three species of Foraminifera were identified:—

Globigerina bulloides.
Bulimina ovata.
Uvigerina pygmæa.

One fish vertebra was found. There are no siliceous organisms. The insoluble residue is grey-green as at the last station.

Station 65 : Gulf of Oman ; depth 907 metres ; small Bigelow sample ; green, slightly calcareous mud ; mud 96·6% ; organic remains 3·5%.

Pelagic remains :—

Foraminifera.

Globigerina bulloides.
Gl. dubia.
Pulleniatina obliquiloculata.
Globorotalia canariensis.
Gl. menardii.

Benthic remains :—

Foraminifera.

Textularia agglutinans.
Verneulina scabra.
Pyrgo murrhina.
Nonion umbilicatulum.
Bulimina ovata.
B. pyrula.
B. subornata.
Virgulina subsquamosa.
Uvigerina pygmæa.
U. schwageri.
Cancris auriculus.
Planulina arimensis.
Pl. wuellerstorfi.
Laticarinina pauperata.

The only other remains present are a few vertebræ, scales and otoliths of fish.

Station 66 : Gulf of Oman ; depth 609 metres ; small Bigelow sample ; green, calcareous mud ; mud 94·6% ; organic remains 5·4%.

Pelagic remains :—

Foraminifera.

Globigerina bulloides.
Gl. dubia.
Globigerinoides rubra.
Globorotalia menardii.

Benthic remains :—

Foraminifera.

Textularia sagittula.
Sigmoilina schlumbergeri.
Robulus calcar.
Bulimina ovata.
Bolivina beyrichi.
Uvigerina pygmæa.
Uvigerina tenuistriata.
Valvulineria allomorphinoides.
Cancris auriculus.
Ehrenbergina pacifica.
Cibicides lobatulus.

Foraminifera are not very common in this deposit. Other remains are absent. There are no siliceous organisms.

Station 67 : Gulf of Oman ; depth 274 metres ; coarse and intact dredge samples ; green mud with Pteropod shells, limestone pebbles and igneous rock ; mud 96·0% ; organic remains 4·0%.

Chief components.	Frequency.	% coarse material.	% deposit.
Pteropoda	A	78·0	3·1
Other remains	R	22·0	0·9
		100·0	4·0

Pelagic remains :—

Foraminifera.

Globigerina bulloides.
Gl. dubia.
Orbulina universa.
Pulleniatina obliquiloculata.

Pteropoda.

Limacina inflata.
Creseis acicula.
Cr. virgula.
Hyalocylis striata.
Diacria quadridentata.
Cavolinia longirostris.
Atlanta sp.

Benthic remains :—

Foraminifera.

Textularia sp.
Clavulina angularis.
Cl. pacifica.
Spiroloculina sp.
Triloculina sp.
Nodosaria pauciloculata.
Nodosaria pyrula.
Saracenaria italica.
Bulimina pyrula.
Uvigerina pygmœa.
Rotalia margaritifera.
Cancris auriculus.

Mollusca.

Argonauta sp.
Rostellaria sp.

In addition to the above, other Mollusc, Echinoderm, coral and Crustacean remains occur sparingly. A few fish otoliths and bones are present. The mud contains large numbers of small fæcal pellets.

Station 70 : Gulf of Oman ; depth 196 metres ; small Bigelow sample ; grey-green mud ; mud 86·8% ; organic remains 13·2%.

Pelagic remains :—

Foraminifera.

Globigerina bulloides.
Globigerinoides rubra.

Pteropoda.

Creseis sp.

Benthic remains :—

Foraminifera.

Clavulina angularis.
Lagena sp.
Bolivina dilatata.
Rotalia calcar.
Cancris auriculus.
Ehrenbergina pacifica.

No siliceous organisms were observed.

Station 72 : Gulf of Oman ; depth 73 metres ; coarse Agassiz trawl sample and mud from Lamellibranch shells ; calcareous conglomerate, shells and shell gravel ; mud from bivalves gave : mud 84·6% ; organic remains 15·4%.

Chief components.	Frequency.	% coarse material.	% deposit.
Foraminifera	F	1·6	0·3
Polychæta	F	2·5	0·4
Crustacea	VC	10·1	1·5
(*Balanus*)	(F)	(3·5)	(0·6)
Lamellibranchiata	A	58·5	9·0
Gasteropoda	C	13·0	2·0
Pteropoda	F	2·6	0·4
Other remains	F	11·7	1·8
		100·0	15·4

Benthic remains :—

Foraminifera.

Reophax sp.	*Nonion scaphum.*
Textularia agglutinans.	? *Nonionella auris.*
T. gramen.	*Elphidium* ? *articulatum.*
T. porrecta.	*El. craticulatum.*
Quinqueloculina sp.	*Eponides præcinctus.*
Spiroloculina grateloupi var. *acescata.*	*Rotalia calcar.*
	R. margaritifera.
Triloculina tricarinata.	*R. papillosa.*
Lenticulina rotulata.	*Miniacina miniacea.*
Nonion grateloupi.	

It is possible that the mud contained in the bivalves is not representative of the deposit, as the shells may have been filled by the finer components of the sediment being drifted into them. The Gasteropoda are almost entirely of one species of *Turritella*. A few small solitary corals occur on some of these shells. Abundant fragments of shells and worm-tubes are visible in the calcareous conglomerate. Fragments of encrusting Polyzoa and *Balanus* spp. occur in the sand and gravel, evidently derived from these organisms growing on the conglomerate rock.

Station 73 : Gulf of Oman ; depth 91 metres ; coarse and intact Priestman grab samples ; very sandy, green mud with Molluscan remains ; mud 35·5% ; organic remains 64·5% (These values are only approximate, as much of the finer material consists of finely triturated shell fragments.)

Chief components.	Frequency.	% coarse material.	% deposit.
Foraminifera	F	1·9	1·2
Polychæta	F	3·9	2·5
Echinodermata	F	2·1	1·4
Crustacea	VC	10·1	6·5
(*Balanus*)	(C)	(6·6)	(4·3)
Lamellibranchiata	A	46·5	30·0
Gasteropoda	C	12·1	7·8
Pteropoda	F	2·4	1·5
Scaphopoda	R	0·1	0·1
Other remains	C	20·9	13·5
		100·0	64·5

Pelagic remains :—

Foraminifera.

Globigerina bulloides.	*Globigerinella æquilateralis.*
Gl. dubia.	*Orbulina universa.*
Globigerinoides sacculifera.	*Globorotalia menardii.*

Pteropoda.

Limacina inflata.	*Hyalocylis striata.*
Creseis acicula.	*Cavolinia longirostris.*
Cr. virgula.	*Atlanta* sp.

Benthic remains :—

Foraminifera.

Reophax sp.
Textularia agglutinans.
T. conica.
T. semialata.
Quinqueloculina sp.
Massilina arenaria.
Spiroloculina depressa.
Triloculina tricarinata.
Robulus gibbus.
Bolivina beyrichi var. *alata.*
Eponides præcinctus.
Rotalia margaritifera.
R. papillosa.

Rare fragments of Polyzoa and solitary corals, Alcyonarian spicules and Ostracod valves occur.

Station 74 : Gulf of Oman ; depth 155 metres ; coarse Priestman grab sample ; probably sandy green mud as at the previous two stations.

Chief components.	Frequency.	% coarse material.
Foraminifera	F	4·4
Corals	R	2·7
Polychæta	VC	10·6
Polyzoa	F	3·0
Echinodermata	F	5·5
Crustacea	VC	9·6
Lamellibranchiata	C	15·5
Gasteropoda	VC	25·3
Pteropoda	C	8·0
Scaphopoda	F	3·3
Pisces	F	5·5
Other remains	F	6·6
		100·0

Pelagic remains :—

Foraminifera.

Globigerina bulloides.
Globigerinoides sacculifera.
Globigerinella æquilateralis.
Orbulina universa.
Pulleniatina obliquiloculata.

Pteropoda.

Limacina inflata.
Creseis acicula.
Cr. virgula.
Diacria quadridentata.
Cavolinia longirostris.
C. uncinata.
Atlanta sp.

Benthic remains :—

Foraminifera.

Quinqueloculina sp.
Spiroloculina depressa.
Triloculina tricarinata.
Pyrgo depressa.
Robulus sp.
Nodosaria vertebralis.
Virgulina sp.
Bolivina sp.
Eponides præcinctus.
Rotalia margaritifera.
R. papillosa.
Miniacina miniacea.

Polychæt tubes and Gasteropoda are much commoner here than at the two previous stations, but bivalve remains are fewer. Ostracod valves, fish vertebræ and Alcyonarian spicules are present (see Pl. I, fig. 2).

Station 75 : Gulf of Oman : depth 201 metres ; Priestman grab samples ; impure Pteropod ooze ; mud 61·0% ; organic remains 39·0%.

Chief components.	Frequency.	% coarse material.	% deposit.
Polychæta	C	5·2	2·0
Polyzoa	F	3·8	1·5
Echinodermata	C	7·5	3·0
Crustacea	C	7·0	2·7
Lamellibranchiata	R	4·4	1·7
Gasteropoda	VC	24·9	9·7
Pteropoda	A	28·7	11·2
(*Creseis*)	(A)	(15·8)	(6·2)
Scaphopoda	C	6·6	2·6
Pisces	F	4·4	1·7
Other remains	C	7·5	2·9
		100·0	39·0

Pelagic remains :—

Foraminifera.

Globigerina bulloides. *Globorotalia menardii.*

Pteropoda.

Creseis acicula. *Diacria quadridentata.*

Hyalocylis striata. *Cavolinia longirostris.*

This Pteropod ooze consists largely of the straight-shelled species, *Creseis acicula* (see Pl. III, fig. 2). Both pelagic and neritic Foraminifera are scarce. Pieces of Brachyuran carapaces and Stomatopod chelæ are recognizable among the crustacean remains. A few fish vertebræ and a shark's tooth were found.

Station 76 : Gulf of Oman ; depth 3289 metres ; small Bigelow sample ; grey calcareous mud ; mud 95·2% ; organic remains 4·8%.

This deposit contains very few organic remains. No siliceous organisms or Foraminifera were found nor shell fragments. One Ostracod valve was the only animal fragment recovered. A few cinder particles, quartz grains and other mineral grains occur.

Station 77 : South Arabian Coast ; depth 411 metres ; coarse Priestman grab sample only ; green Pteropod mud, smelling strongly of hydrogen sulphide ; only washed material from this station was preserved.

Chief components.	Frequency.	% coarse material.
Polychæta	F	2·3
Crustacea	F	3·4
Lamellibranchiata	F	17·1
Gasteropoda	F	
Pteropoda	A	22·5
Pisces	A	28·3
Other remains	A	26·4
		100·0

Pelagic remains :—

Foraminifera.

Orbulina universa.	*Globorotalia menardii.*
Pulleniatina obliquiloculata.	

Pteropoda.

Peraclis reticulata.	*Clio pyramidata.*
Creseis acicula.	*Diacria quadridentata.*
Cr. virgula.	*Cavolinia longirostris.*
Hyalocylis striata.	*Atlanta* sp.

The commonest animal remains are bones and scales of fish. Otoliths, however, are not common. Mollusca, other than Pteropoda, are rare. The "other remains" consist largely of unseparated mud particles and carbonaceous granules, which are rather common. The only benthic Foraminifera identified were *Robulus gibbus* and *Eponides præcinctus.*

Station 79 : South Arabian Coast ; depth 102 metres ; small Bigelow sample ; friable green mud, smelling of hydrogen sulphide ; mud 94·0% ; organic remains 6·0%.

Pelagic remains :—

Foraminifera.

Globigerina bulloides.	*Globigerinoides rubra.*
Globigerinoides conglobata.	*Globorotalia menardii.*

Organic remains are rare in this sediment. Benthic Foraminifera are represented by *Robulus* sp., which is fairly common, and by rare specimens of *Uvigerina pygmæa.* Molluscan remains are rare. A few fish bones are present. Siliceous organisms are represented by fragmentary sponge spicules and a few *Coscinodiscus* sp.

Station 80 : South Arabian Coast ; depth 16–22 metres ; debris material only ; coarse sand and shell.

Only a small amount of sand and a few large fragments are preserved. Shells of *Terebra, Conus* and *Dentalium* occur. The sand is in part siliceous and part calcareous. The usual shallow-water organisms are present. *Elphidium* sp., *Planulina* sp., *Rotalia* sp. and *Quinqueloculina* sp. were the only Foraminifera identified. A few solitary corals are present.

Station 81 : Northern Arabian Sea ; depth 3351 metres ; Bigelow and coarse net sample ; grey calcareous mud ; mud 95·0% ; organic remains 5·0%.

Pelagic remains are represented by three species of Foraminifera, *Globigerina bulloides, G. dubia,* and *Globigerinoides conglobata,* and two of Pteropoda, *Diacria quadridentata* and *Cavolinia longirostris.* Molluscan remains are the commonest organic remains in the deposit. Echinoderm fragments and fish remains also occur. A few *Coscinodiscus* sp. are the only siliceous remains identified. Animal remains are rather rare in this deposit, but small carbonaceous particles, presumably cinders, are rather common.

Station 85 : Northern Arabian Sea ; depth 1687 metres ; small Bigelow sample ; grey calcareous mud ; mud 91·6% ; organic remains 8·4%.

Pelagic remains :—

Foraminifera :

Globigerina bulloides.
Gl. dubia.
Globigerinoides rubra.
Gl. sacculifera.
Orbulina universa.
Pulleniatina obliquiloculata.
Globorotalia menardii.

Pteropoda.

Limacina inflata.
Atlanta sp.

Very few benthic remains are present in this deposit (see Pl. I, fig. 1) ; *Pyrgo depressa* and *Cibicides lobatulus* are the only Foraminifera identified. No Molluscan or Echinoderm remains were found, and the only other materials of organic origin are a few otoliths and very rare fragments of Poriferan spicules.

Station 87 : Northern Arabian Sea ; depth 582 metres ; small Bigelow sample ; grey, gritty, calcareous mud with numerous Foraminifera ; mud 55·2% ; organic remains 44·8%.

Pelagic remains :—

Foraminifera.

Globigerina bulloides.
Gl. dubia.
Globigerinoides conglobata.
Gl. rubra.
Gl. sacculifera.
Globigerinella æquilateralis.
Globigerinella digitata.
Orbulina universa.
Pulleniatina obliquiloculata.
Sphæroidinella dehiscens.
Globorotalia menardii.

Pteropoda.

Creseis sp.

Benthic remains are represented by Lamellibranch fragments and the following four Foraminifera :—

Dentalina filiformis.
Bolivina dilatata.
Cancris auriculus.
Ehrenbergina serrata.

No siliceous remains were found in this material. A considerable amount of organic matter appears to be present. The deposit is a rather impure Globigerina ooze.

Station 88 : Northern Arabian Sea ; depth 274 metres ; Priestman grab samples ; light grey, calcareous clay, smelling faintly of H_2S when fresh, with a thin superficial layer of dark brown mud ; mud 87·3% ; total organic remains 12·7% ; coarse organic remains 1·9%.

Chief components.	Frequency.	% coarse material.	% deposit.
Lamellibranchiata	VC	25·4	0·5
Gasteropoda	F	10·1	0·2
Pteropoda	A	33·3	0·6
Pisces	C	6·3	0·1
Other groups	F	7·8	0·2
Calcareous residue	F	17·1	0·3
		100·0	1·9

Pelagic remains :—

Foraminifera.

Globigerina bulloides. *Globigerinoides rubra.*

Pteropoda.

Creseis acicula. *Cavolinia longirostris.*
Cr. virgula. *C. uncinata.*
Hyalocylis striata. *Atlanta* sp.
Diacria quadridentata.

Benthic remains :—

Foraminifera.

Robulus acutauricularis. *Bulimina pyrula.*
Bulimina elongata. *Uvigerina bifurcata.*
B. ovata. *U. pygmœa.*

A considerable part of the animal remains consists of very fine, white calcareous particles, presumably of Molluscan origin, but too small for identification. In calculating the percentage of the deposit contributed by the different phyla this fine material has been ignored. The final column (% deposit) in the above table has been calculated on the coarse animal remains only.

Station 89 : Northern Arabian Sea ; depth 193 metres ; coarse Priestman grab sample ; no intact material ; sand, shell and rock.

Chief components.	Frequency.	% coarse material.
Foraminifera	R	0·1
Polychæta	R	0·4
Echinodermata	R	0·9
Crustacea	R	0·2
Lamellibranchiata	C	15·1
Gasteropoda	C	12·7
Pteropoda	R	1·9
Pisces	R	0·2
Other remains	A	68·5
		100·0

Pelagic remains :—

Pteropoda.

Limacina inflata. *Diacria quadridentata.*
Creseis acicula. *Cavolinia longirostris.*
Cr. virgula. *C. uncinata.*
Hyalocylis striata. *Atlanta* sp.

No pelagic Foraminifera were identified. *Operculina granulosa* and *Heterostegina operculinoides* were the only benthic species identified. The coarse material at this station consists of calcareous rubble, most of which is unidentifiable ; some appears to be derived from large shells, a few fragments of which occur ; most of the Molluscan material consists of small shells and shell-fragments. Foraminifera are notable by their absence; only a very few worn specimens are present in the material.

Station 92 : Central Arabian Sea ; depth 3722 metres ; Bigelow sample ; creamy Globigerina ooze, light brown when wet ; mud 85·9% ; organic remains 14·1%.

Pelagic remains :—

Foraminifera.

Globigerina bulloides.
Gl. dubia.
Globigerinoides rubra.
Globigerinoides sacculifera.
Pulleniatina obliquiloculata.
Globorotalia menardii.

This is a nearly pure Globigerina ooze. There are very few intact tests of Foraminifera present, and benthic forms are absent. A few Coccoliths are present and also a few fragments of *Coscinodiscus* sp.

Station 93 : Central Arabian Sea ; depth 3991 metres ; Bigelow sample ; transitional Globigerina ooze-red clay ; mud 90·4% ; organic remains 9·6%.

Pelagic remains :—

Foraminifera :

Globigerina bulloides.
Gl. dubia.
Globigerinoides conglobata.
Pulleniatina obliquiloculata.
Globorotalia menardii.

No other organic remains, calcareous or siliceous, are present. Very few of the Foraminifera are intact.

Station 100 : Central Arabian Sea ; depth 4082 metres ; Bigelow sample ; red clay.

The red clay forms almost 100% of this deposit. No Foraminifera were sifted out, and there is a very low calcium carbonate content. Siliceous remains present include various kinds of Poriferan spicules and diatom frustules including *Coscinodiscus* sp., mainly in a fragmentary condition. No Radiolaria are present.

Station 101 : Central Arabian Sea ; depth 5285 metres ; Bigelow sample ; red clay.

This deposit is very similar to that from the preceding station. No calcareous remains were found, and the same siliceous organisms as at Sta. 100 are present.

Station 102 : Central Arabian Sea ; depth 3215 metres ; Bigelow sample ; Globigerina ooze ; mud 79·3% ; organic remains 20·7%.

Pelagic remains :—

Foraminifera.

Globigerina bulloides.
Gl. dubia.
Globigerinoides conglobata.
Gl. rubra.
Gl. sacculifera.
Orbulina universa.
Pulleniatina obliquiloculata.
Globorotalia menardii.
Gl. tumida.

No Pteropoda are present, and no benthic Foraminifera. The only benthic remains found were a few Poriferan spicules. *Coscinodiscus* frustules are again present, as at the last two stations, and also a few Radiolarian skeletons.

This Globigerina ooze is impure, containing some red clay, but the remains of pelagic Foraminifera are very common, so that the clay only imparts a faint creamy colour to the deposit. The apparently complete absence of benthic Foraminifera is noteworthy as these tests are often common in Globigerina ooze.

Station 103 : Zanzibar area ; depth 101 metres ; Priestman grab samples ; grey-green, incoherent, gritty mud with much siliceous sand and gravel ; mud 74·6% ; sand and gravel 11·3% ; organic remains 14·1%.

Chief components.	Frequency.	% coarse material.	% deposit.
Foraminifera	A	6·9	1·8
Corals	R	2·6	0·7
Polychæta	R	0·5	0·1
Polyzoa	VC	6·8	1·7
Echinodermata	F	3·9	1·0
Crustacea	F	4·3	1·1
Lamellibranchiata	VC	19·8	5·0
Gasteropoda	F	7·2	1·8
Pteropoda	R	1·8	0·5
Scaphopoda	R	0·7	0·2
Pisces	R	0·4	0·1
Other remains	A	45·1	11·4
		100·0	25·4

The " Other remains " in the above list include unidentifiable calcareous grains and carbonaceous particles as well as quartz grains (see Pl. II, fig. 3).

Pelagic remains :—

Pteropoda.

Creseis acicula.
Cr. virgula.
Clio pyramidata.
Diacria quadridentata.
Cavolinia globulosa.
C. longirostris.
Atlanta sp.

No pelagic Foraminifera were found.

Benthic remains :—

Foraminifera.

Textularia agglutinans.
T. corrugata.
T. sagittula var. *atrata.*
T. tuberosa.
Sigmoilina schlumbergeri.
Triloculina tricarinata.
Pyrgo sarsi.
Placopsilina cenomana.
Robulus convergens.
R. costatus var. *multicostatus.*
R. orbicularis.
Nodosaria flinti.
N. subscalaris.
Vaginulina legumen.
Nonion ? asterizans.
Nonion scaphum.
Elphidium craticulatum.
El. crispum.
Operculina granulosa.
Heterostegina operculinoides.
Sorites marginalis.
Uvigerina tenuistriata.
Rotalia papillosa.
Amphistegina radiata.
Cibicides lobatulus.
Planorbulinella larvata.
Carpenteria monticularis.
C. proteiformis.
Miniacina miniacea.

Corals.

Diaseris sp.

The majority of the animal remains have been pulverized into small fragments, perhaps owing to their being rolled about along with the quartz grains. Many of the Foraminifera, particularly specimens of *Operculina granulosa*, are discoloured and blackened. Presumably all these specimens were dead before being collected, and had become affected by contact with the mud. On dissolving out the calcium carbonate of the test with acid, green casts are left. The dark colour is apparently due to this contained material (? glauconite), as no sulphide of iron appears to be present.

The greenish colour of the mud is in part due to contained organic matter, some of which was dissolved out by the alcohol used to preserve the sample of the deposit. Some of the colour is due to the presence of the green mineral material in the deposit.

Station 104: Zanzibar Area: depth 207 metres; Priestman grab samples; grey-green mud similar to that from Sta. 103, but finer and more coherent; mud 75·7%; sand and gravel 16·6%; organic remains 7·7%.

Chief components.	Frequency.	% coarse material.	% deposit.
Foraminifera	C	1·4	0·4
Corals	F	6·2	1·5
Polychæta	F	3·6	0·9
Polyzoa	R	0·7	0·2
Echinodermata	F	5·0	1·2
Crustacea	R	0·5	0·1
Lamellibranchiata	R	3·6	0·9
Gasteropoda	R	5·8	1·4
Pteropoda	F	4·6	1·1
Scaphopoda	R	0·1	tr.
Pisces	R	0·1	tr.
Other remains	C	68·4	16·6
		100·0	24·3

Pelagic remains :—

Pteropoda.

Creseis acicula. *Cavolinia longirostris.*
Cr. virgula.

No pelagic Foraminifera were identified.

Benthic remains :—

Foraminifera.

Textularia sagittula. *Robulus orbicularis.*
Spiroloculina depressa. *Lenticulina rotulata.*
Sigmoilina schlumbergeri. *Marginulina glabra.*
Pyrgo comata. *Nodosaria flinti.*
P. depressa. *Frondicularia plicata.*
P. vespertilio. *Operculina granulosa.*
Robulus costatus var. multicostatus. *Amphistegina radiata.*
Cibicides lobatulus.
R. iota.

Cirripedia.

Verruca sp. *Balanus* sp.

Station 105 : Zanzibar Area ; depth 280 metres ; Agassiz trawl sample ; clayey grey mud with very few animal remains ; mud 98·1% ; sand 0·4% ; organic remains 1·5%.

Chief components.	Frequency.	% coarse material.	% deposit.
Foraminifera	C	19·3	0·4
Corals	R	1·8	tr.
Polychæta	R	0·4	tr.
Polyzoa	R	0·9	tr.
Echinodermata	F	5·0	0·1
Crustacea	R	0·6	tr.
Lamellibranchiata	F	5·9	0·1
Gasteropoda	F	11·3	0·2
Pteropoda	VC	15·1	0·3
Pisces	F	3·6	0·1
Other remains	F	36·1	0·7
		100·0	1·9

No pelagic Foraminifera were found in this deposit.

Benthic remains :—

Foraminifera.

Storthosphæra albida.
Pilulina jeffreysi.
Tholosina bulla.
Dendrophrya ramosa.
Aschemonella sp.
Ammodiscoides turbinatus.
Tolypammina vagans.
Ammolagena clavata.
Haplophragmoides subglobosum.
Textularia gramen.
Valvulina conica.
V. fusca.
Clavulina communis.
Cl. parisiensis.
Pyrgo depressa.
Biloculinella globula.
Robulus costatus.
R. costatus var. *multicostatus.*
R. echinatus.
R. iota.
Lenticulina rotulata.
Nodosaria soluta.
Saracenaria italica.
Operculina granulosa.
Bulimina ovata.
Rotalia papillosa.
Epistomina elegans.

A few valves of *Balanus* sp. occur in this material and a considerable number of specimens of *Cavolinia longirostris.* This Pteropod is the only pelagic organism found in the deposit. Fragments of coal, cinders and decayed pieces of timber cored by *Teredo* sp. are frequent. The large arenaceous Foraminiferan, *Dendrophrya ramosa* Cushman, is very abundant, and forms the bulk of the material left after washing out the mud (see Pl. IV, fig. 1).

Station 106 : Zanzibar Area ; depth 212 metres ; Bigelow sample ; grey-green calcareous mud ; mud 90·1% ; organic remains 9·9%.

Pelagic remains :—

Foraminifera.

Globigerina bulloides.	*Globigerinoides rubra.*
Gl. dubia.	*Orbulina universa.*

Pteropoda.

Limacina inflata.	*Atlanta* sp.
Creseis virgula.	

Benthic remains are not very abundant. Molluscan and Echinoderm remains are only rare or frequent and only two benthic Foraminifera were identified, namely, *Pilulina jeffreysi* and *Triloculina* sp. A few sponge spicules were the only siliceous remains found.

Station 108 : Zanzibar Area ; depth 781 metres ; Bigelow sample ; brown-grey calcareous mud ; mud 96·2% ; organic remains 3·8%.

Pelagic remains :—

Foraminifera.

Globigerina bulloides.	*Orbulina universa.*
Gl. dubia.	*Pulleniatina obliquiloculata.*
Globigerinoides rubra.	*Globorotalia menardii.*
Gl. sacculifera.	

Benthic remains are very rare at this station. A few gasteropod fragments and Ostracod valves occur. Only two benthic Foraminifera, *Quinqueloculina* sp. and *Triloculina* sp., were found. Poriferan spicule fragments were the only siliceous remains seen.

Station 109 : Zanzibar Area ; depth 640 metres ; Agassiz trawl debris ; light grey mud.

No proper sample of the deposit at this station was preserved. The following organisms were found in debris :

Pteropoda.

Clio pyramidata.	*Diacria trispinosa.*
Cuvierina columnella.	

Foraminifera.

Rhabdammina abyssorum.	*Amphisorus hemprichi.*
Pyrgo sp.	

In addition, fragments of Lamellibranchiata, Gasteropoda, Scaphopoda and Echinodermata, particularly spines, occurred. Many of the Echinoderm spines had specimens of the Cirripede *Heteralepas typica* Nilsson-Cantell attached to them.

Station 110 : Zanzibar Area ; depth 329 metres ; Bigelow sample and materials from Otter trawl ; transitional from brown mud to Globigerina ooze ; an impure Globigerina ooze ; mud 37·9% ; organic remains 62·1%.

Pelagic remains :—

Foraminifera.

Globigerina bulloides.	*Orbulina universa.*
Gl. dubia.	*Pulleniatina obliquiloculata.*
Globigerinoides sacculifera.	*Globorotalia menardii.*

Pteropoda.

Limacina inflata.	*Cavolinia* sp.
Creseis sp.	*Atlanta* sp.

Benthic remains :—

Molluscan remains are rare, but fragments of *Verruca* sp. are common and Ostracod valves frequent. Some cinders are present and one piece of pumice was preserved, but the chief benthic remains are Foraminifera, which are abundant both in numbers and species. A list follows :

Reophax agglutinans.
R. bilocularis.
R. guttifer.
Ammodiscus incertus.
Tolypammina vagans.
Ammolagena clavata.
Haplophragmoides sp.
Ammobaculites calcareum.
Spiroplectammina milletti.
Textularia conica.
T. sagittula var. *fistulosa.*
Clavulina communis.
Sigmoilina schlumbergeri.
Pyrgo denticulata.
P. depressa.
P. murrhina.
Cornuspira carinata.
Planispirina sphaera.
Trochammina squamata.
Robulus costatus.
R. iota.
Lenticulina rotulata.
Planularia tricarinella.
Vaginulina linearis.
Nonion pacificum.
N. pompilioides.
Bulimina ovata.
B. pyrula.
Uvigerina aculeata.
U. brunnensis.
Siphogenerina striata var. *curta.*
Angulogerina carinata.
Gyroidina soldani.
Rotalia papillosa.
Epistomina elegans.
Cancris auriculus.
Anomalina balthica.
Planulina ariminensis.
Pl. wuellerstorfi.
Cibicides lobatulus.
Carpenteria monticularis.
C. proteiformis.

Station 111 : Zanzibar Area ; depth 73–165 metres ; no intact sample.

The bottom would appear to be composed largely of calcareous rubble or conglomerate formed of fragments of shells and other neritic animals, cemented with fine calcareous material and overgrown with attached Polyzoa, *Lithothamnion*, etc. Dead *Balani* and their valves are of frequent occurrence. Attached Foraminifera and Polychæt tubes are common. The following Foraminifera were found in a small spirit-preserved sample of sand.

Pelagic :—

Globigerina bulloides.
Globigerina dubia.

Benthic :—

Spiroloculina depressa.
Triloculina sp.
Placopsilina cenomana.
Robulus sp.
Heterostegina sp.
Alveolinella boscii.
Amphistegina radiata.
Planorbulinella larvata.
Carpenteria monticularis.
C. proteiformis.
C. utricularis.
Sporadotrema cylindricum.
C. mesentericum.
Miniacina miniacea.

Alcyonarian spicules and *Stenohelia* fragments are present in the fine sand preserved with the conglomerate.

Station 112 : Zanzibar Area ; depth 113 metres ; coarse material from Priestman grab only ; shallow-water sand of quartz grains and organic calcareous structures.

The material contains fragments of the usual shallow-water fauna, including many Foraminifera. Pelagic organisms are represented by *Globigerinoides rubra* and two Pteropods, *Diacria trispinosa* and *Cavolinia longirostris*, only. Among benthic organisms, fragments of the Polyzoan *Haswellia* and a Gasteropod, probably *Vermetus* sp., occur. The following Foraminifera were identified :—

Textularia agglutinans.
Gaudryina rugulosa.
Quinqueloculina sp.
Spiroloculina depressa.
Triloculina tricarinata.
Pyrgo murrhina.
Robulus orbicularis.
Robulus sp.
Nodosaria scalaris.
Elphidium crispum.
Heterostegina operculinoides.
Amphisorus hemprichi.
Alveolinella boscii.
Sphæridia papillata.
Amphistegina radiata.
Planorbulinella larvata.
Sporadotrema cylindricum.
Sp. mesentericum.
Miniacina miniacea.

Station 113 : Zanzibar Area ; depth 220 metres ; Priestman grab samples ; grey-brown muddy sand ; mud 53·9% ; mineral grains 38·0% ; organic remains 8·1%.

Chief components.	Frequency.	% coarse material.	% deposit.
Foraminifera	F	0·6	0·3
Alcyonaria	F	0·6	0·3
Corals	R	0·4	0·2
Polychæta	R	0·3	0·1
Polyzoa	R	0·6	0·3
Echinodermata	F	2·0	0·9
Crustacea	F	3·7	1·7
Lamellibranchiata	R	3·5	1·6
Gasteropoda	R	4·5	2·1
Pteropoda	R	0·7	0·4
Scaphopoda	R	0·3	0·1
Pisces	R	0·3	0·1
Other remains	A	82·5	38·0
		100·0	46·1

The "Other remains" consist for the most part of quartz grains and some unidentifiable calcareous material.

Pelagic remains :—

Foraminifera.

Globigerina bulloides.
Orbulina universa.
Globorotalia menardii.

Pteropoda.

Limacina inflata.
Creseis acicula.
Creseis virgula.

Benthic remains :—

Foraminifera.

Textularia gramen.
T. trochus.
Gaudryina rugulosa.
Spiroloculina depressa.
Sigmoilina schlumbergeri.
Triloculina tricarinata.
Pyrgo vespertilio.
Nubecularia tuberosa.
Robulus sp.
Vaginulina linearis.
Nonion umbilicatulum.
Operculina granulosa.
Heterostegina suborbicularis.
Sorites marginalis.
Marginopora vertebralis.
Uvigerina aculeata.
Epistomina elegans.
Amphistegina radiata.
Planorbulinella larvata.
Gypsina vesicularis.
Carpenteria monticularis.

The calcareous remains are much broken and worn, due to grinding against the quartz grains, which are abundant here as at Sta. 103. A number of fragments of Cirripedia are recognizable among the crustacean remains, notably compartments and valves of *Balanus* and *Verruca*. A carina of *Lepas* sp. was found (see Pl. II, fig. 4).

Station 114 : Zanzibar Area ; depth 353 metres ; Priestman grab sample ; impure Globigerina ooze, transitional to brown terrigenous mud ; mud 31·6% ; organic remains 68·4%.

The organic remains in this deposit are almost entirely Foraminifera. No large Molluscan remains occur, the only Mollusca being small larval Gasteropoda no bigger than Globigerinæ.

Pelagic remains :—

Foraminifera.

Globigerina bulloides.
Gl. dubia.
Globigerinoides rubra.
Gl. sacculifera.
Orbulina universa.
Pulleniatina obliquiloculata.
Globorotalia menardii.
Gl. tumida.

Pteropoda.

Limacina inflata.
Creseis sp.
Atlanta sp.

Benthic remains :—

Foraminifera.

Spiroplectammina milletti.
Textularia flinti.
T. gramen.
T. sagittula.
Gaudryina baccata.
Clavulina communis.
Spiroloculina ? tenuis.
Sigmoilina schlumbergeri.
Triloculina sp.
Pyrgo denticulata.
P. depressa.
Cornuspira carinata.
Planispirina sphæra.
Robulus convergens.
R. subaculeatus.
Marginulina glabra.

Nodosaria hirsuta.	*Epistomina elegans.*
Vaginulina legumen.	*Cancris auriculus.*
Bulimina ovata.	*Cymbaloporetta squamosa.*
B. pyrula.	*Chilostomella ovoidea.*
Virgulina subsquamosa.	*Planulina ariminensis.*
Uvigerina aculeata.	*Pl. wuellerstorfi.*
U. tenuistriata.	*Cibicides lobatulus.*
Siphogenerina striata var. *curta.*	

Poriferan spicules are frequent in this deposit. Ostracod valves occur.

Station 115 : Zanzibar Area ; depth 640 metres ; a small tube of debris is the only material.

The debris contained much unidentifiable material and mucoid matter, and yielded very few animal remains. The following Foraminifera were identified :

Globigerina bulloides.	*Globorotalia menardii.*
Gl. dubia.	*Ammodiscus* sp.

Spines and fragments of Echinodermata were the only other remains present.

Station 117 : Zanzibar Area ; depth 889 metres ; Bigelow sample ; light brown calcareous mud or impure Globigerina ooze ; mud 87·6% ; organic remains 12·4%.

Pelagic remains :—

Foraminifera.

Globigerina bulloides.	*Orbulina universa.*
Gl. dubia.	*Pulleniatina obliquiloculata.*
Globigerinoides conglobata.	*Globorotalia menardii.*
Gl. sacculifera.	*Gl. tumida.*

Pteropoda.

Creseis sp.

Pteropoda are only represented by a few small fragments of a species of *Creseis*, not specifically identifiable. No benthic Foraminifera are present in this deposit. Siliceous remains are represented by a few spicule fragments.

Station 118 : Zanzibar Area ; depth 1789 metres ; Bigelow sample ; light grey Globigerina ooze ; mud 70·1% ; organic remains 29·9%.

Pelagic remains :—

Foraminifera.

Globigerina bulloides.	*Orbulina universa.*
Gl. dubia.	*Pulleniatina obliquiloculata.*
Globigerinoides conglobata.	*Sphæroidinella dehiscens.*
Gl. rubra.	*Globorotalia menardii.*
Gl. sacculifera.	*Gl. tumida.*

Pteropoda.

Creseis sp.	*Cavolinia* spp.
Cuvierina columnella.	*Atlanta* sp.

Only one benthic Foraminiferan, a species of *Pyrgo*, was identified from this material. Sponge spicules are frequent and a few Radiolaria are present.

Station 119: Zanzibar Area; depth 1204 metres; Bigelow sample and dried mud from Agassiz trawl; light brown, clayey, Globigerina ooze; mud 55·4%; organic remains 44·6%.

Pelagic remains :—

Foraminifera.

Globigerina bulloides.
Gl. dubia.
Globigerinoides conglobata.
Gl. rubra.
Orbulina universa.
Pulleniatina obliquiloculata.
Sphæroidinella dehiscens.
Globorotalia canariensis.
Gl. crassa.
Gl. menardii.
Gl. truncatulinoides.
Gl. tumida.

Pteropoda.

Cuvierina columnella.

Benthic remains :—

Foraminifera.

Rhabdammina abyssorum.
Rh. discreta.
Rh. linearis.
Marsipella elongata.
Tholosina bulla.
Hyperammina friabilis.
Dendrophrya ramosa.
Reophax nodulosus.
Ammodiscus incertus.
Ammodiscoides turbinatus.
Ammolagena clavata.
Cyclammina compressa.
Verneulina propinqua.
Triloculina sp.
Pyrgo depressa.
P. murrhina.
Lenticulina subalata.
Dentalina filiformis.
Nonion umbilicatulum.
Bolivinita quadrilatera.

A few rare fragments of Mollusca and a few Radiolaria occur, but no other animal remains.

Station 120: Zanzibar Area; depth 2931 metres; Bigelow sample; fawn-grey Globigerina ooze; mud 67·2%; organic remains 32·8%.

Pelagic remains :—

Foraminifera.

Globigerina bulloides.
Gl. dubia.
Globigerinoides conglobata.
Gl. rubra.
Orbulina universa.
Pulleniatina obliquiloculata.
Sphæroidinella dehiscens.
Globorotalia menardii.
Gl. tumida.

No Pteropoda are present.

Benthic remains :—

Foraminifera.

Rhabdammina abyssorum.
Rh. abyssorum var. *radiata.*
Rh. discreta.
Rh. linearis.
Psammosphæra fusca.
Saccammina sphærica.
Hyperammina friabilis.
Reophax nodulosus.
Ammolagena clavata.

No Molluscan or Echinoderm remains are present in this deposit. Poriferan spicules are very rare.

Station 121 : Zanzibar Area ; depth 925 metres ; Bigelow sample ; grey-brown impure Globigerina ooze ; mud 72·7% ; organic remains 27·3%.

Pelagic remains :—

Foraminifera.

Globigerina bulloides.
Globigerinoides conglobata.
Gl. rubra.
Orbulina universa.
Pulleniatina obliquiloculata.
Globorotalia menardii.
Gl. tumida.

Pteropoda.

Limacina inflata.
Diacria quadridentata.

Rare Gasteropod fragments and sponge spicules were the only benthic remains found in this deposit.

Station 122 : Zanzibar Area ; depth 745 metres ; Bigelow sample ; dark grey-brown calcareous mud with Foraminifera ; mud 81·1% ; organic remains 18·9%.

Pelagic remains :—

Foraminifera.

Globigerina bulloides.
Gl. dubia.
Globigerinoides conglobata.
Gl. rubra.
Orbulina universa.
Pulleniatina obliquiloculata.
Globorotalia menardii.

Pteropoda.

Creseis sp.
Cavolinia sp.

Benthic remains are represented by frequent Gasteropod fragments and two Foraminifera, *Pyrgo* sp. and *Ophthalmidium inconstans*, neither of which is common. Poriferan remains are rare.

Station 123 : Zanzibar Area ; depth 256–366 metres ; dredge samples ; grey clayey mud with much quartz sand and rock fragments, but few animal remains ; mud and mineral grains 97·9% ; organic remains 2·1%.

Pelagic remains :—

Foraminifera.

Globigerina sp.
Orbulina universa.
Globorotalia truncatulinoides.

Benthic remains :—

Foraminifera.

Bulimina pyrula.
Chilostomella ovoidea.
Planulina wuellerstorfi.

In addition a few fragments of Pteropoda are present, and among benthic remains a few Echinoderm fragments and some plant remains derived from the land.

The rock fragments obtained are calcareous conglomerate. Some pieces show remains of Mollusca, Polyzoa and Foraminifera. The bottom here appears to be covered by a terrigenous mud interspersed with patches of conglomerate.

Station 125 : Zanzibar Area ; depth 805 metres ; Priestman grab sample ; brown, clayey mud with few organic remains ; mud 92·5% ; organic remains 7·5%.

Pelagic remains :—

Foraminifera.

Globigerina bulloides.
Gl. dubia.
Globigerinoides rubra.
Gl. sacculifera.
Orbulina universa.
Pulleniatina obliquiloculata.
Globorotalia menardii.
Gl. truncatulinoides.

Pteropoda.

Limacina inflata.
Creseis virgula.

Benthic remains :—

Foraminifera.

Crithionina pisum var. *hispida.*
Hormosina globulifera.
Haplostiche dubia.
Ammodiscoides turbinatus.
Spiroplectammina milletti.
Textularia gramen.
T. sagittula.
Quinqueloculina sp.
Spiroloculina depressa.
Triloculina trigonula.
Pyrgo denticulata.
P. vespertilio.
Robulus costatus.
R. ? papillosus.
Lenticulina rotulata.
Nodosaria flinti.
Saracenaria italica.
Nonion umbilicatulum.
Elphidium craticulatum.
El. crispum.
Operculina granulosa.
Heterostegina suborbicularis.
Sorites marginalis.
Amphisorus hemprichi.
Marginopora vertebralis.
Alveolinella boscii.
Buliminella elegantissima.
Bulimina aculeata.
Bolivina seminuda.
Uvigerina aculeata.
U. asperula.
Siphogenerina bifrons.
S. striata var. *curta.*
Eponides præcinctus.
Rotalia papillosa.
Amphistegina radiata.
Laticarinina pauperata.
Gypsina globulus.
Carpenteria proteiformis.

Very young shells of Gastropoda and Lamellibranchiata and fragments of *Tubipora* and *Seriatopora* are the only other remains of bottom-living organisms present.

Station 126 : Zanzibar Area ; depth 209 metres ; coarse Priestman grab sample ; light brown mud and calcareous sand and gravel.

Chief components.	Frequency.	% coarse material.
Foraminifera	C	2·3
Corals	VC	18·2
Polychæta	R	0·1
Polyzoa	R	0·2
Echinodermata	F	1·0
Crustacea	R	1·2

Chief components.	Frequency.	% coarse material.
Lamellibranchiata	R	3·1
Gasteropoda	F	6·5
Pteropoda	R	0·7
Algæ	VC	16·8
Other remains	A	49·9
		100·0

Pelagic remains :—

Foraminifera.

Globigerina sp.
Globorotalia menardii.

Pteropoda.

Creseis acicula.
Cr. virgula.
Diacria quadridentata.
Cavolinia longirostris.
Atlanta sp.

Benthic remains :—

Foraminifera.

Reophax sp.
Haplostiche dubia.
Textularia gramen.
T. sagittula.
Clavulina parisiensis.
Quinqueloculina sp.
Massilina arenaria.
Spiroloculina depressa.
Pyrgo comata.
P. sarsi.
Biloculinella globula.
Placopsilina cenomana.
Robulus orbicularis.
Robulus sp.
Vaginulina wetherellii
Nodosaria sp.
Nonion pompilioides.
Elphidium crispum.
Operculina granulosa.
Heterostegina depressa.
H. operculinoides.
H. suborbicularis.
Sorites marginalis.
Amphisorus hemprichi.
Marginopora vertebralis.
Amphistegina radiata.
Planorbulinella larvata.
Gypsina globulus.
Carpenteria proteiformis.
Homotrema rubrum.
Sporadotrema cylindricum.
Sp. mesentericum.

Corals.

Cycloseris sp.
Pachyseris sp.
Seriatopora sp.
Acropora sp.
Tubipora sp.

Remains of Alcyonacea and Hydrocorallinæ are also present. Otoliths and sponge spicules occur infrequently. Among Gasteropod remains a specimen of *Xenophora* sp. was recognized, but the majority of the Molluscan fragments are unidentifiable. Among the Crustacean remains *Balanus* valves are frequent.

Station 127 : Southern Arabian Sea ; depth 4091 metres ; Bigelow sample ; Globigerina ooze transitional to Red clay ; mud 51·1% ; organic remains 48·9%.

Pelagic remains :—

Foraminifera.

Globigerina bulloides.
Gl. dubia.
Globigerinoides conglobata.
Gl. rubra.
Orbulina universa.
Pulleniatina obliquiloculata.
Sphæroidinella dehiscens.
Globorotalia menardii.
Gl. tumida.

No calcareous benthic remains are present and no Pteropod shells. A few sponge spicules and a few Radiolaria occur. This deposit and the following three are all transitional to Red clay. This one is the nearest to Globigerina ooze. That from Sta. 134 is most like Red clay, and has the smallest percentage (15·97) of Foraminiferal tests of the four. Sta. 134 is also the deepest of the three.

Station 128 : Southern Arabian Sea ; depth 4060 metres ; Bigelow sample ; Globigerina ooze transitional to Red clay, similar to the preceding ; mud 78·1% ; organic remains 21·9%.

Pelagic remains :—

Foraminifera.

Globigerina bulloides.
Gl. dubia.
Globigerinoides conglobata.
Pulleniatina obliquiloculata.
Sphæroidinella dehiscens.
Globorotalia menardii.
Gl. tumida.

No Pteropod shells are present. Benthic organisms are represented by *Rotalia* sp., and, among siliceous organisms, by sponge spicules and Radiolaria.

Station 132 : Southern Arabian Sea ; depth 4082 metres ; Bigelow sample ; like Stas. 127 and 128, Globigerina ooze transitional to Red clay ; mud 75·2% ; organic remains 24·8%.

Most of the fragments of Foraminifera are unidentifiable. The following four pelagic species occur :—

Globigerina dubia.
Globigerinoides conglobata.
Pulleniatina obliquiloculata.
Globorotalia menardii.

Probably other species are represented among the fragments of tests. A very few Coccoliths occur in this deposit. Only one benthic Foraminiferan, *Pyrgo murrhina*, was found. Fragmentary Radiolaria and a few Diatom frustules are to be found in the deposit.

Station 133 : Southern Arabian Sea ; depth 3385 metres ; no deposit is available for this station. A single Foraminiferan, *Triloculina tricarinata*, was found in debris.

Station 134 : Southern Arabian Sea ; depth 4234 metres ; Bigelow sample ; like Stas. 127, 128 and 132, this is a transitional deposit, but in this case much nearer to Red clay ; mud 84·0% ; organic remains 16·0%.

Pelagic remains :—

Foraminifera.

Globigerina bulloides.
Gl. dubia.
Gl. inflata.
Globigerinoides sacculifera.
Orbulina universa.
Pulleniatina obliquiloculata.
Sphæroidinella dehiscens.
Globorotalia menardii.
Gl. tumida.

Only one benthic Foraminiferan, *Virgulina subsquamosa*, occurred in the upper part of this deposit. A few *Lithocircus* sp. and *Coscinodiscus* sp. are the only siliceous remains present.

Station 135 : Southern Arabian Sea ; Bigelow sample ; Globigerina ooze ; mud 55·5% ; organic remains 44·5%.

Pelagic remains :—

Foraminifera.

Globigerina bulloides.
Gl. dubia.
Globigerinoides conglobata.
Gl. rubra.
Gl. sacculifera.
Globigerinella æquilateralis.
Gl. digitata.
Orbulina universa.
Pulleniatina obliquiloculata.
Sphæroidinella dehiscens.
Globorotalia canariensis.
Gl. crassa.
Gl. menardii.
Gl. tumida.

Benthic remains :—

Foraminifera : Two species only, *Rotalia brœkhiana* and *Planulina wuellerstorfi*, were found in the surface deposit.

Pulleniatina obliquiloculata is very common in the surface deposit. Radiolarian skeletons are common at this station.

Station 137 : Maldive Area ; depth 46 metres ; Priestman grab samples ; fine grey-white, calcareous mud, smelling of sulphuretted hydrogen ; mud 91·1% ; organic remains 8·9%.

Chief components.	Frequency.	% coarse material.	% deposit.
Foraminifera	R	0·3	tr.
Echinodermata	F	3·3	0·3
Crustacea	F	3·3	0·3
Lamellibranchiata	F	5·4	0·5
Gasteropoda	A	80·2	7·1
Pteropoda	F	3·4	0·3
Other remains	R	4·1	0·4
		100·0	8·9

Pelagic remains :—

No pelagic Foraminifera were found.

Pteropoda.

Creseis acicula.
Creseis virgula.

Benthic remains :—

Foraminifera.

Textularia foliacea.
Operculina gaimardi.
O. granulosa.
Heterostegina suborbicularis.
Amphistegina radiata.

This deposit is probably true coral mud derived from the breakdown of calcareous animal and plant structures growing on the reef. According to an estimation made at

the time of collecting, the water drawn off from the mud contained 4·90 mgrm. H_2S per litre.

Station 139: Maldive Area; depth 57 metres; Priestman grab samples; fine, calcareous, shell and Foraminiferal sand; mud 12·8%; organic remains 87·2%.

Chief components.	Frequency.	% coarse material.	% deposit.
Foraminifera	A	61·2	53·4
Echinodermata	F	2·2	1·9
Crustacea	R	1·6	1·4
Lamellibranchiata	R	4·6	3·9
Gasteropoda	F	10·8	9·5
Halimeda	R	1·8	1·6
Other remains	VC	17·8	15·5
		100·0	87·2

The only pelagic organism found was a specimen of the Foraminiferan *Tretomphalus bulloides*.

Benthic remains:—

Foraminifera.

Textularia candeina.
T. conica.
T. foliacea.
T. gramen.
T. pseudotrochus.
Spiroloculina grateloupi.
Triloculina oblonga.
Tr. tricarinata.
Placopsilina cenomana.
Elphidium craticulatum.
Operculinella cumingi.
Operculina granulosa.
Heterostegina depressa.
Alveolinella boscii.
Amphistegina radiata.
Cymbaloporetta bradyi.
C. squamosa.
Gypsina vesicularis.
Carpenteria proteiformis.
C. utricularis.
Sporadotrema cylindricum.
Miniacina miniacea.

Fragments of corals, *Cryptohelia*, Alcyonacea, Scaphopoda and Polychæta also occur in this deposit (see Pl. III, fig. 3).

Station 141: Maldive Area; depth 44 metres; Priestman grab samples; calcareous sand with much *Halimeda*; fine sand 49·4%; organic remains 50·6%.

Chief components.	Frequency.	% coarse material.	% deposit.
Foraminifera	A	13·0	6·6
Lamellibranchiata	C	9·2	4·7
Gasteropoda	R	3·9	2·0
Halimeda	A	41·0	20·7
Other remains	VC	32·9	16·6
		100·0	50·6

Benthic remains :—

Foraminifera.

Textularia candeina.	*Operculina gaimardi.*
Quinqueloculina kerimbatica.	*O. granulosa.*
Q. parkeri.	*Heterostegina depressa.*
Spiroloculina tenuissima.	*Borelis melo.*
Schlumbergerina alveoliniformis.	*Alveolinella boscii.*
Triloculina tricarinata.	*Amphistegina radiata.*
Robulus sp.	*Acervulina inhærans.*
Elphidium craticulatum.	*Gypsina globulus.*
Operculinella cumingi.	*Miniacina miniacea.*

Corals, Hydrocorallinæ, Alcyonarian spicules, Echinoderm and Crustacean fragments occur in small quantities. Pelagic remains are practically absent, the only organism observed being *Atlanta* sp.

Station 142a : Maldive Area ; depth 31 metres ; Priestman grab samples ; coral mud smelling of H_2S ; mud 59·7% ; organic remains 40·3%.

Chief components.	Frequency.	% coarse material.	% deposit.
Foraminifera	VC	4·5	1·8
Alcyonaria	F	1·0	0·4
Echinodermata	R	0·5	0·2
Crustacea	F	4·4	1·8
Lamellibranchiata	A	33·3	13·4
Gasteropoda	C	16·1	6·5
Halimeda	R	2·0	0·8
Other remains	A	38·2	15·4
		100·0	40·3

The animal remains are very finely triturated. This accounts for the large percentage of " Other remains " in the above table, all the unidentifiable material being included under this head.

Benthic remains :—

Foraminifera.

Textularia conica.	*Operculina granulosa.*
T. foliacea.	*Heterostegina depressa.*
T. haueri.	*Amphisorus hemprichi.*
Quinqueloculina reticulata.	*Borelis melo.*
Massilina inæqualis.	*Alveolinella boscii.*
Elphidium craticulatum.	*Amphistegina radiata.*
Operculina gaimardi.	*Gypsina globulus.*

Alcyonarian spicules, Hydrocorallinæ, *Seriatopora*, otoliths and Scaphopoda occur in small numbers. The Echinoderm remains are chiefly those of Clypeastroidea. Very few pelagic Foraminifera or Pteropoda are present. Estimations made when the sample was collected gave the amount of H_2S present as 3·92 mgrm. per litre of water aspirated off from the mud.

Station 142b: Maldive Area; depth 37 metres; Priestman grab samples; coral mud with very few coarse fragments; mud 93·0%; organic remains 7·0%.

Chief components.	Frequency.	% coarse material.	% deposit.
Echinodermata	C	7·0	0·5
Crustacea	VC	11·2	0·8
Lamellibranchiata	VC	21·1	1·5
Gasteropoda	A	51·5	3·6
Pteropoda	R	0·8	tr.
Other remains	F	8·4	0·6
		100·0	7·0

Benthic remains :—

Foraminifera.

Quinqueloculina ferussacii.
Spiroloculina canaliculata.
Sp. grateloupi.
Operculina gaimardi.
O. granulosa.

Poriferan spicules, Polyzoa, Scaphopoda, otoliths and bones of fish and fragments of *Halimeda* occur sparingly. The Echinoderm remains are again largely those of Clypeastroidea. No large fragments of any of the above organisms occur in this deposit. Slightly less H_2S was found at this station, 2·26 mgrm. per litre of aspirated water, as against 3·92 mgrm. at the last station (see Pl. III, fig. 6).

Station 143; Maldive Area; depth 797 metres; Agassiz trawl sample; grey-green Foraminiferal sand; mud 22·0%; organic remains 78·0%.

This sample has probably had some of the finer material washed out during its passage to the surface, and so the above figures can only be regarded as very approximate.

Pelagic remains :—

Foraminifera.

Globigerina bulloides.
Gl. dubia.
Globigerinoides conglobata.
Gl. rubra.
Orbulina universa.
Pulleniatina obliquiloculata.
Globorotalia canariensis.
Gl. menardii.

Pteropoda.

Limacina inflata.
Creseis acicula.

Benthic remains :—

Foraminifera.

Reophax scorpiurus.
Haplostiche dubia.
Haplophragmoides scitulum.
Ammobaculites calcareum.
Textularia conica.
T. gramen.
T. sagittula.
Verneulina bradyi.
Gaudryina baccata.
Clavulina parisiensis.
Massilina arenaria.
Spiroloculina depressa.
Sigmoilina schlumbergeri.
Pyrgo anomala.
P. milletti.
P. murrhina.
Cornuspira involvens.
Robulus sp.

Saracenaria italica.	*Siphogenerina columellaris.*
Polymorphina lanceolata.	*Epistomina elegans.*
Heterostegina depressa.	*Cancris auriculus.*
Alveolinella boscii.	*Amphistegina radiata.*
Bulimina elongata.	*Chilostomella ovoidea.*

Ostracod valves, otoliths and Echinoderm spines also occur. The greenish colour of this deposit is due to the contents of the Foraminiferal tests. When the tests are dissolved away, green casts, presumably of glauconite, are left.

Station 144 : Maldive Area ; depth 31 metres ; Priestman grab samples ; coarse sand and gravel composed mainly of molluscan and *Halimeda* fragments ; mud 57·3% ; organic remains 42·7%.

Chief components.	Frequency.	% coarse material.	% deposit.
Foraminifera	R	1·4	0·6
Corals	F	4·4	1·9
Echinodermata	R	0·8	0·3
Lamellibranchiata	C	12·0	5·1
Gasteropoda	A	50·1	21·4
Halimeda	VC	15·6	6·7
Calcareous conglomerate	C	15·7	6·7
		100·0	42·7

No pelagic remains are present in this deposit.

Benthic remains :—

Foraminifera.

Textularia candeina.	*Marginopora vertebralis.*
T. conica.	*Borelis melo.*
Operculinella cumingi.	*Alveolinella boscii.*
Heterostegina depressa.	*Amphistegina radiata.*
H. suborbicularis.	*Miniacina miniacea.*

Alcyonarian spicules, Polychæt tubes, Scaphopods and fragments of *Lithothamnion* occur sparingly. *Balanus* compartments are among the Crustacean materials present. Clypeastroid fragments are again more numerous than those of other Echinoidea (see Pl. III, fig. 4).

Some of the material is cemented together, forming a loose conglomerate. There is no H_2S present at this station.

Station 145 : Maldive Area ; depth 494 metres ; Baillie rod sample ; grey-green mud and sand ; mud 51·7% ; organic remains 48·3%.

Pelagic remains :—

Foraminifera.

Globigerina bulloides.
Gl. dubia.
Globigerinoides conglobata.
Gl. rubra.
Gl. sacculifera.
Orbulina universa.
Pulleniatina obliquiloculata.
Globorotalia canariensis.
Gl. menardii.

Pteropoda.

Limacina bulimoides.
L. inflata.
Creseis acicula.
Hyalocylis striata.
Diacria quadridentata.

Benthic remains :—

Foraminifera.

Reophax sp.
Haplostiche dubia.
Spiroplectammina milletti.
Textularia sagittula.
Gaudryina baccata.
Massilina arenaria.
Triloculina oblonga.
Pyrgo vespertilio.
Biloculinella globula.
Bulimina aculeata.
Uvigerina schwageri.
Siphogenerina columellaris.
Epistomina elegans.
Cancris auriculus.
Cymbaloporetta squamosa.
Chilostomella ovoidea.
Planulina wuellerstorfi.

This deposit is a mixture of coral mud, Foraminiferal sand and Globigerina ooze, of which it is perhaps nearest to the Globigerina ooze. A few otoliths occur.

Station 147 : Maldive Area ; depth 27 metres ; Priestman grab samples ; coral mud and gravel ; mud 93·3% ; organic remains 6·7%.

Chief components.	Frequency.	% coarse material.	% deposit.
Corals	F	7·8	0·5
Polychæta	A	28·6	1·9
Echinodermata	C	11·7	0·8
Crustacea	A	18·3	1·2
Lamellibranchiata	C	15·4	1·0
Gasteropoda	C	14·5	1·0
Pteropoda	R	1·1	0·1
Halimeda	R	2·6	0·2
		100·0	6·7

Pelagic remains are represented by *Creseis acicula* only. Two benthic Foraminifera only were found, *Heterostegina depressa* and *Amphistegina radiata.* A few Polyzoan and Scaphopod remains occur.

No H_2S was present in this deposit from the lagoon.

Station 149 : Maldive Area ; depth 238 metres ; coarse Priestman grab sample only ; coarse gravel and sand composed of shell, coral and coralline algæ.

Chief components.	Frequency.	% coarse material.
Foraminifera	C	5·0
Corals	A	20·7
Hydrocorallinæ	R	0·7
Alcyonaria	R	0·3
Polychæta	R	tr.
Polyzoa	R	0·5
Echinodermata	R	0·3
Crustacea	R	0·3
Lamellibranchiata	R	1·1
Gasteropoda	F	10·9
Pteropoda	R	0·2
Halimeda	A	28·0
Other remains	A	32·0
		100·0

Pelagic remains :—

Foraminifera.

Globigerina bulloides.
Pulleniatina obliquiloculata.
Globorotalia menardii.

Benthic remains :—

Foraminifera.

Haplcstiche dubia.
Textularia agglutinans.
Quinqueloculina kerimbatica.
Pyrgo denticulata.
P. milletti.
Biloculinella globula.
Robulus ? lucidus.
R. orbicularis.
Lenticulina rotulata.
Lingulina grandis.
Elphidium craticulatum.
Operculinella cumingi.
Heterostegina depressa.
H. operculinoides.
H. suborbicularis.
Sorites marginalis.
Amphisorus hemprichi.
Marginopora vertebralis.
Alveolinella boscii.
Siphogenerina raphanus.
Amphistegina radiata.
Calcarina defranci.
Cymbaloporetta bradyi.
Cibicides lobatulus.
Planorbulinella larvata.
Gypsina globulus.
Carpenteria monticularis.
C. proteiformis.
C. utricularis.
Sporadotrema cylindricum.
Sp. mesentericum.
Miniacina miniacea.

Station 152: Maldive Area; depth 878 metres; dredge samples; grey impure Globigerina ooze; mud 34·4%; organic remains 65·6%.

Pelagic remains :—

Foraminifera.

Globigerina bulloides.
Gl. dubia.
Globigerinoides conglobata.
Globigerinoides rubra.
Gl. sacculifera.
Globigerinella digitata.

Orbulina universa.
Pulleniatina obliquiloculata.
Sphæroidinella dehiscens.
Globorotalia canariensis.
Gl. menardii.
Gl. truncatulinoides.
Gl. tumida.

Pteropoda.

Limacina bulimoides.
L. inflata.
L. trochiformis.
Creseis virgula.
Diacria quadridentata.

Benthic remains :—

Foraminifera.

Aschemonella ramuliformis.
Pyrgo murrhina.
Dentalina elegans.
Saracenaria italica.
Elphidium crispum.
Sorites marginalis.
Angulogerina carinata.
Epistomina elegans.

Poriferan spicules and pieces of siliceous sponge skeletons are fairly common, but for the most part microscopic. The coarse sievings from a large bulk of deposit yielded a few worn coral fragments, a few mollusc shells, Echinoderm remains, and pieces of calcareous rock containing shell fragments and Foraminifera.

Station 153 : Maldive Area ; depth 256 metres ; pieces of calcareous rock and a few animal remains from a dredge sample of the bottom are the only materials available. The following Foraminifera are represented :

Pelagic :—

Globorotalia canariensis.
Gl. crassa.
Tretomphalus bulloides.

Benthic :—

Textularia conica.
Nodosaria scalaris.
Robulus sp.
Marginulina sp.
Marginopora vertebralis.
Angulogerina carinata.
Cibicides refulgens.
C. biserialis.
Planorbulinoides retinaculata.
Miniacina miniacea.

Fragments of Lamellibranchiata, Gasteropoda (incl. *Xenophora* sp.), Echinodermata, Corals (*Diaseris* sp.), Crustacea and Polychæta and otoliths occur sparingly. Shell fragments and Foraminifera can be seen in the calcareous conglomerate.

Station 156 : Maldive Area ; depth 1317 metres ; Baillie rod sample ; Globigerina ooze ; mud 67·2% ; organic remains 32·8%.

Pelagic remains :—

Foraminifera.

Globigerina bulloides.
Gl. dubia.
Globigerinoides conglobata.
Gl. rubra.
Gl. sacculifera.
Globigerinella digitata.
Orbulina universa.
Pulleniatina obliquiloculata.
Sphæroidinella dehiscens.
Globorotalia canariensis.
Gl. menardii.

Benthic remains :—

Foraminifera.

Clavulina communis.	*Epistomina elegans.*
Nodosaria pauperata.	*Cibicides lobatulus.*

A few fragments of Coral (? *Galaxea* sp.) are present.

Station 157 : Maldive Area ; depth 229 metres ; calcareous rock.

Very few incrusting organisms are present. The Foraminifera, *Carpenteria monticularis, C. proteiformis* and *C. utricularis* are present, and also the Stylasterine *Cryptohelia stenopoma.* A few young solitary corals and fragments of Oculinidæ and *Flabellum* sp. occur. The following Pteropoda occur :

Cuvierina columnella.	*Cavolinia longirostris.*
Cavolinia gibbosa.	*C. uncinata.*
C. globulosa.	

Station 158 : Maldive Area ; depth 914 metres ; coarse Agassiz sample only ; calcareous rock as at the previous station.

Pelagic remains :—

Foraminifera.

Globigerina bulloides.	*Pulleniatina obliquiloculata.*
Globigerinoides conglobata.	*Globorotalia menardii.*
Orbulina universa.	

Benthic remains :—

Foraminifera.

Clavulina communis.	*Cancris auriculus.*
Sorites marginalis.	*Laticarinina pauperata.*
Bulimina ovata.	*Cibicides lobatulus.*
Gyroidina soldani.	

Molluscan remains are rare. Only one species of Pteropod, *Cavolinia uncinata*, is present. Brachiopod valves, a shell of *Verruca* sp., and *Cryptohelia* sp. were found.

Station 159 : Maldive Area ; depth 1280 metres ; trawl samples ; cream-coloured calcareous, probably coral, mud ; mud 94·5% ; organic remains 5·5%.

Pelagic remains :—

Foraminifera.

Globorotalia canariensis.	*Globorotalia crassa.*

Pteropoda.

Creseis acicula.	*Hyalocylis striata.*

Benthic remains :—

Foraminifera.

Textularia agglutinans.	*Triloculina oblonga.*
T. foliacea.	*T. tricarinata.*
Gaudryina baccata.	*Cymbaloporetta bradyi.*
Spiroloculina grateloupi var. *acescata.*	*C. squamosa.*
	Cymbaloporella tabellæformis.

Young hyaline shells of Lamellibranchiata and Gasteropoda make up the rest of the organic remains.

Station 160 : Maldive Area ; depth 37 metres ; Priestman grab samples ; coral mud smelling of H_2S ; mud 94·6% ; organic remains 5·4%.

Chief components.	Frequency.	% coarse material.	% deposit.
Crustacea	VC	10·0	0·5
Lamellibranchiata	A	36·6	2·0
Gasteropoda	F	10·7	0·6
Pteropoda	A	20·6	1·1
Halimeda	R	1·8	0·1
Other animals	R	0·4	tr.
Calcareous residue	C	19·9	1·1
		100·0	5·4

Pelagic remains :—

Foraminifera.

Globigerina bulloides.
Gl. dubia.
Globigerinoides conglobata.
Gl. rubra.
Gl. sacculifera.
Globigerinella digitata.
Orbulina universa.
Globorotalia canariensis.
Gl. crassa.
Gl. menardii.

Pteropoda.

Creseis acicula.
Diacria quadridentata.
Cavolinia longirostris.

Benthic remains :—

Foraminifera.

Bathysiphon filiformis.
Aschemonella ramuliformis.
Trochamminoides proteus.
Clavulina communis.
Pyrgo vespertilio.
Dentalina emaciata.
Nodosaria pyrula.
Nonion boueanum.
Epistomina elegans.
Laticarinina pauperata.

A few fish-bones are present in this deposit. *Globigerinella digitata* is much commoner at this station than elsewhere.

Station 161 : Maldive Area ; depth 46 metres ; Priestman grab samples ; coarse coral and shell sand and mud ; mud 68·5% ; organic remains 31·5%.

Chief components.	Frequency.	% coarse material.	% deposit.
Foraminifera	A	14·0	4·4
(*Alveolinella boscii*)	(A)	(4·1)	(1·3)
Coral	R	1·8	0·5
Polychæta	R	0·5	0·2
Echinodermata	R	0·2	0·1
Crustacea	R	0·7	0·2
Lamellibranchiata	C	12·1	3·8
Gasteropoda	C	19·9	6·3
Halimeda	C	7·8	2·4
Other remains	A	43·0	13·6
		100·0	31·5

Pelagic remains :—

Only a few fragments of Pteropoda.

Benthic remains :—

Foraminifera.

Textularia candeina.
T. conica.
T. foliacea.
Massilina australis.
Elphidium craticulatum.
El. crispum.
Operculinella cumingi.
Operculina granulosa.
Heterostegina depressa.
Marginopora vertebralis.
Borelis melo.
Alveolinella boscii.
Amphistegina radiata.
Calcarina defranci.
Homotrema rubrum.
Sporadotrema cylindricum.
Miniacina miniacea.

Corals are represented by worn fragments of perforate corals and by small specimens of *Diaseris* sp. Many of the Polychæt tubes are formed of agglutinated Foraminifera and shell fragments. The abundance of tests of *Alveolinella boscii* and *Operculinella cumingi* is noteworthy.

Station 163 : Maldive Area ; depth 274 metres ; Priestman grab samples ; greenish-white mud with coral and shell sand ; mud 64·1% ; organic remains 35·9%.

Chief components.	Frequency.	% coarse material.	% deposit.
Foraminifera	C	4·5	1·6
Alcyonaria	F	1·2	0·4
Hydrocorallinæ	F	1·2	0·4
Corals	F	4·1	1·5
Polyzoa	F	2·8	1·0
Echinodermata	F	2·3	0·8
Crustacea	F	4·9	1·8
Lamellibranchiata	F	5·7	2·1
Gasteropoda	VC	19·0	6·8
Pteropoda	R	0·9	0·3
Pisces	R	0·8	0·3
Halimeda	F	3·4	1·2
Other remains	A	49·2	17·7
		100·0	35·9

Pelagic remains :—

Foraminifera.

Globigerina bulloides.
Gl. dubia.
Globigerinoides conglobata.
Gl. sacculifera.
Orbulina universa.
Pulleniatina obliquiloculata.
Globorotalia menardii.

Pteropoda.

Limacina inflata.
Creseis acicula.
Cr. virgula.
Clio cuspidata.
Diacria quadridentata.
Cavolinia uncinata.
Atlanta sp.

Benthic remains :—

Foraminifera.

Textularia rugosa.
Triloculina oblonga.
Lenticulina rotulata.
Operculinella cumingi.
Operculina granulosa.
Heterostegina depressa.
H. operculinoides.
H. suborbicularis.
Sorites marginalis.
Amphisorus hemprichi.
Marginopora vertebralis.
Borelis melo.
Alveolinella boscii.
Uvigerina pygmæa.
Rotalia calcar.
Amphistegina radiata.
Calcarina defranci.
Chilostomella ovoidea.
Homotrema rubrum.
Sporadotrema mesentericum.
Miniacina miniacea.

The Gasteropod remains are riddled with holes presumably the borings of sponges or algæ. The green colour of this deposit appears to be due to the presence of organic matter and chlorophyll and not to glauconite (see Pl. III, fig. 5).

Station 164 : Maldive Area ; depth 183 metres ; Priestman grab samples ; greenish calcareous sand and mud, chiefly shell and coral debris ; mud 69·5% ; organic remains 30·5%.

Chief components.	Frequency.	% coarse material.	% deposit.
Foraminifera	C	4·8	1·5
Alcyonaria	F	1·1	0·3
Corals	VC	16·8	5·1
Polychæta	F	2·6	0·8
Polyzoa	VC	6·3	1·9
Echinodermata	R	0·9	0·3
Crustacea	F	4·6	1·4
Lamellibranchiata	F	5·2	1·6
Gasteropoda	VC	24·1	7·3
Pteropoda	R	0·5	0·2
Halimeda	VC	11·5	3·5
Other animals	R	0·1	tr.
Other remains	VC	21·5	6·6
		100·0	30·5

Pelagic remains :—

Foraminifera.

Globigerina bulloides.
Gl. dubia.
Globigerinoides conglobata.
Globigerinella æquilateralis.
Orbulina universa.
Pulleniatina obliquiloculata.
Sphæroidinella dehiscens.
Globorotalia canariensis.
Gl. menardii.

Pteropoda.

Limacina inflata.
Creseis acicula.
Clio pyramidata.
Diacria quadridentata.
Cavolinia longirostris.
C. uncinata.
Atlanta sp.

Benthic remains :—

Foraminifera.

Textularia agglutinans.
T. rugosa.
Verneulina triquetra.
Gaudryina rugulosa.
Pyrgo denticulata.
Lenticulina d'Orbignyi.
L. rotulata.
Nodosaria subscalaris var. *paucicostata.*
Lingulina grandis.
Elphidium craticulatum.
Operculinella cumingi.
Operculina gaimardi.
Heterostegina depressa.
H. operculinoides.
Heterostegina suborbicularis.
Sorites marginalis.
Borelis melo.
Alveolinella boscii.
Rotalia calcar.
Amphistegina radiata.
Calcarina defranci.
Cymbaloporetta bradyi.
Planorbulinella larvata.
Gypsina globulus.
Homotrema rubrum.
Sporadotrema cylindricum.
Sp. mesentericum.
Miniacina miniacea.

A few fragments of Hydrocorallinæ and Scaphopoda and otoliths occur. The green colour again appears to be due to organic matter.

Station 165 : Maldive Area ; depth 366 metres ; Priestman grab sample ; greenish calcareous sand ; mud 13·7% ; organic remains 86·3%.

It is possible that this sample is not intact, some of the fine mud having, in all probability, been washed out.

Pelagic remains :—

Foraminifera.

Globigerina bulloides.
Gl. dubia.
Globigerinoides conglobata.
Gl. sacculifera.
Orbulina universa.
Pulleniatina obliquiloculata.
Sphæroidinella dehiscens.
Globorotalia menardii.

Pteropoda.

Limacina bulimoides.
L. inflata.
Cavolinia longirostris.
Atlanta sp.

Benthic remains :—

Foraminifera.

Reophax sp.
Ammobaculites calcareum.
Textularia sp.
Quinqueloculina sp.
Pyrgo denticulata.
P. vespertilio.
Biloculinella globula.
Dentalina filiformis.
Elphidium crispum.
Heterostegina suborbicularis.
Amphisorus hemprichi.
Alveolinella boscii.
Cancris auriculus.
Amphistegina radiata.
Calcarina defranci.
Miniacina miniacea.

Fragments of Alcyonaria, Echinodermata, Pteropoda, Gasteropoda and Lamellibranchiata occur, but there is no large amount of sifted material from which to work out their relative abundance.

Station 166 : Central Arabian Sea ; depth 4793 metres ; Bigelow sample ; pure Red clay with only a trace of calcium carbonate. Neither calcareous nor siliceous remains were found in this deposit.

Station 167 : Central Arabian Sea ; depth 4042 metres ; Bigelow sample ; transitional between Globigerina ooze and Red clay ; mud 86·6% ; organic remains 13·4%.

Pelagic remains (see Pl. II, fig. 6) :—

Foraminifera.

Globigerina bulloides. *Sphæroidinella dehiscens.*
Globigerinoides conglobata. *Globorotalia menardii.*
Pulleniatina obliquiloculata. *Gl. tumida.*

No benthic remains were found in this deposit. Radiolarian skeletons were present but rare.

Station 170 : Central Arabian Sea ; depth 3676 metres ; Baillie rod sample ; creamy-grey Globigerina ooze.

Pelagic remains :—

Foraminifera.

Globigerina bulloides. *Globigerinoides sacculifera.*
Gl. dubia. *Globorotalia menardii.*
Globigerinoides rubra. *Gl. tumida.*

Diatoms.

Coscinodiscus sp.

No benthic remains were found. This ooze is exceedingly fine, and contains very few whole Foraminiferal tests and no other calcareous organisms. Siliceous remains are represented by *Coscinodiscus* sp. and a few Radiolaria, including *Lithocircus* sp.

Station 173 : Central Arabian Sea ; depth 4499 metres ; Bigelow sample ; Globigerina ooze ; mud 76·6% ; organic remains 23·4%.

Pelagic remains :—

Foraminifera.

Globigerina bulloides. *Globorotalia menardii.*
Gl. dubia. *Gl. tumida.*
Pulleniatina obliquiloculata.

Benthic remains :—

Foraminifera.

Nodosaria sp. *Chilostomella ovoidea.*

Siliceous remains are represented by *Coscinodiscus* sp., Radiolaria and Poriferan spicules ; all are rare.

Station 175 : Gulf of Aden ; depth 1618 metres ; Bigelow sample ; green calcareous mud ; mud 89·7% ; organic remains 10·3%.

Pelagic remains :—

Foraminifera.

Globigerina bulloides.	*Pulleniatina obliquiloculata.*
Gl. dubia.	*Globorotalia canariensis.*
Globigerinoides rubra.	*Gl. crassa.*
Gl. sacculifera.	*Gl. menardii.*
Hastigerina pelagica.	*Gl. tumida.*
Orbulina universa.	

Benthic remains :—

Foraminifera.

Sigmoilina edwardsi.	*Bulimina aculeata.*
Pyrgo murrhina.	*B. pyrula.*
P. sarsi.	*Virgulina squamosa.*
Nonion umbilicatulum.	*Uvigerina pygmæa.*

A few otoliths, sponge spicules, Radiolaria and *Coscinodiscus* sp. are present. The green colour is largely due to the presence of organic matter.

Station 176 : Gulf of Aden ; depth 695 metres ; Agassiz trawl sample ; green coprolitic and Globigerina mud ; mud 44·6% ; fæcal pellets and fine animal remains 49·3% ; larger organic remains 6·1%.

Chief components.	Frequency.	% coarse material.	% deposit.
Foraminifera	A	4·7	0·3
Foraminifera (as Polychæt tubes)	A	16·9	1·0
Porifera	R	0·2	tr.
Corals	F	6·1	0·4
Polychæta	R	0·6	tr.
Echinodermata	F	2·3	0·2
Crustacea	R	0·4	tr.
Lamellibranchiata	C	9·2	0·6
Gasteropoda	VC	27·9	1·7
Pteropoda	VC	18·2	1·1
Scaphopoda	F	3·7	0·2
Pisces	C	6·2	0·4
Other remains	R	3·6	0·2
		100·0	6·1

Pelagic remains :—

Foraminifera.

Globigerina bulloides.	*Pulleniatina obliquiloculata.*
Gl. dubia.	*Globorotalia canariensis.*
Globigerinoides sacculifera.	*Gl. menardii.*
Orbulina universa.	

Pteropoda.

Limacina inflata.
Creseis acicula.
Hyalocylis striata.
Clio pyramidata.
Cuvierina columnella.
Diacria quadridentata.
Cavolinia longirostris.
C. uncinata.
Atlanta sp.

Benthic remains :—

Foraminifera.

Ammobaculites calcareum.
Spiroplectammina milletti.
Textularia sagittula.
Gaudryina baccata.
Clavulina communis.
Spiroloculina depressa.
Pyrgo murrhina.
Robulus calcar.
Lenticulina calcarata.
Nodosaria flinti.
Nodosaria radicula.
N. subscalaris.
Uvigerina pygmæa.
Siphogenerina striata var. *curta.*
Epistomina elegans.
Cancris auriculus.
Ehrenbergina pacifica.
Chilostomella ovoidea.
Planulina wuellerstorfi.
Cibicides lobatulus.

Vertebræ, other bones and otoliths of fish, and sharks' teeth occur in this deposit. Lamellibranch remains are common, including *Cuspidaria* sp., and *Amussium* sp. Gasteropod remains include broken shells of *Xenophora, Ranella, Pleurotoma, Solarium* and *Ianthina.* Scaphopoda are more frequent than usual ; a few fragments of Cephalopod jaws occur. Many of the Polychæt tubes are formed almost entirely of Foraminifera, particularly *Globorotalia menardii.* These agglutinated tubes have been assessed separately in the above table. Small *Globigerinæ* are very common in this deposit, and form roughly half of the 49·3% of fæcal pellets and fine remains. Mineral grains, larger than silt size, are very rare at this station.

Station 178 : Gulf of Aden ; depth 91 metres ; Priestman grab samples ; green, calcareous sand ; fine sand 76·0% ; organic remains 24·0%.

Chief components.	Frequency.	% coarse material.	% deposit.
Foraminifera	R	1·0	0·3
Polychæta	R	1·0	0·3
Polyzoa	R	0·4	0·1
Echinodermata	R	1·4	0·3
Crustacea	R	0·9	0·2
Lamellibranchiata	F	7·7	1·9
Gasteropoda	VC	20·8	5·0
Pteropoda	R	0·1	tr.
Scaphopoda	R	0·1	tr.
Pisces	R	0·8	0·2
Lithothamnion	R	2·9	0·7
Other remains	A	62·6	14·9
Quartz grains	R	0·3	0·1
		100·0	24·0

Pelagic remains :—

Foraminifera.

Globigerina bulloides.

Pteropoda.

Creseis acicula. *Cavolinia longirostris.*
Clio pyramidata.

Benthic remains :—

Foraminifera.

Haplophragmoides grandiformis. *Elphidium macellum.*
Textularia agglutinans. *Operculina gaimardi.*
Spiroloculina grateloupi. *O. granulosa.*
Triloculina tricarinata. *Heterostegina operculinoides.*
Robulus sp. *Sorites marginalis.*
Nodosaria scalaris. *Rotalia papillosa.*
Vaginulina linearis. *Amphistegina radiata.*
Sigmoidella elegantissima. *Planorbulinella larvata.*
Polymorphina ovata. *Miniacina miniacea.*

A few Scaphopoda of the genus *Cadulus* and a few fragments of the bivalve, *Venus torresiana*, occur. Apart from the Gasteropoda and to a lesser extent the Lamellibranchiata all the remains are rare. Alcyonarian spicules and small solitary corals occur occasionally.

A large proportion of the organic remains are worn and unidentifiable calcareous grains. Identifiable remains are comparatively rare. Very little fine mud is present in the samples. This may be due to washing during the passage of the material through the water. Alternatively, this may be the natural state of the deposit, especially as all the remains are much broken and worn, and often rounded as if water-worn (see Pl. II, fig. 2).

Station 179a : Gulf of Aden ; depth 310 metres : Priestman grab and Agassiz trawl samples ; green, sandy mud ; mud 84·8% ; organic remains and rock fragments 15·2%.

Chief components.	Frequency.	% coarse material.	% deposit.
Lamellibranchiata	C	9·1	1·4
Gasteropoda	F	9·4	1·4
Pteropoda	VC	14·4	2·2
Scaphopoda	C	11·1	1·7
Other remains	A	56·0	8·5
		100·0	15·2

The " Other remains " are chiefly rock fragments.

Pelagic remains :—

Foraminifera.

Globigerina bulloides. *Globigerinella æquilateralis.*
Gl. dubia. *Orbulina universa.*
Globigerinoides conglobata. *Globorotalia canariensis.*
Gl. sacculifera. *Gl. menardii.*

Pteropoda.

Limacina inflata.
L. trochiformis.
Creseis acicula.
Cr. virgula.
Clio pyramidata.
Cavolinia longirostris.
Atlanta sp.

Benthic remains :—

Foraminifera.

Textularia sagittula var. *atrata.*
Massilina australis.
Spiroloculina grateloupi.
Nonion scaphum.
Bulimina pupoides.
Bolivina amygdalæformis.
B. beyrichi.
B. simpsoni.
Uvigerina brunnensis.
Uvigerina pygmæa.
U. tenuistriata.
Siphogenerina bifrons.
Angulogerina carinata.
Cancris auriculus.
Cymbaloporetta bradyi.
Cymbaloporella tabellæformis.
Chilostomella ovoidea.
Cibicides lobatulus.

Animal remains in this deposit form only 6·7% of the 15·2% coarse material given in the above table. The rest of this is rock fragments and some unidentified particles. Otoliths and Echinoderm remains occur infrequently. The Pteropod remains are all broken with the exception of the small shells of *Limacina.* Primordial shells of *Creseis* and *Clio* are very common in the fine material sifted out.

Station 179b : Gulf of Aden ; depth 275 metres ; Priestman grab samples ; green, sandy mud ; mud 92·2% ; organic remains 7·8%.

Chief components.	Frequency.	% coarse material.	% deposit.
Corals	R	1·2	0·1
Polychæta	R	1·7	0·1
Echinodermata	A	24·7	1·9
Crustacea	R	1·3	0·1
Lamellibranchiata	VC	19·0	1·5
Gasteropoda	VC	27·5	2·1
Pteropoda	VC	13·5	1·1
Pisces	R	1·0	0·1
Other remains	F	10·1	0·8
		100·0	7·8

Pelagic remains :—

Foraminifera.

Globigerina bulloides.
Globigerinoides sacculifera.
Globigerinella æquilateralis.
Globorotalia menardii.

Pteropoda.

Limacina inflata.
L. trochiformis.
Creseis acicula.
Cr. virgula.
Hyalocylis striata.
Clio pyramidata.
Diacria quadridentata.
Cavolinia longirostris.
C. uncinata.
Atlanta sp.

Benthic remains :—

Foraminifera.

Textularia gramen.
T. pseudocarinata.
Spiroloculina depressa.
Triloculina sp.
Robulus sp.
Elphidium crispum.
Heterostegina operculinoides.
Uvigerina pygmæa.
Amphistegina radiata.
Ehrenbergina pacifica.
Carpenteria utricularis.

Fragments of *Lithothamnion* and sponge spicules occur rarely. Valves of *Venus torresiana* are common.

Station 180 : Gulf of Aden ; depth 397 metres ; Priestman grab samples ; green sandy mud ; mud 92·7% ; organic remains 7·3%.

Chief components.	Frequency.	% coarse material.	% deposit.
Foraminifera	F	0·1	tr.
Echinodermata	C	7·6	0·5
Crustacea	R	0·1	tr.
Lamellibranchiata	A	54·6	4·0
Gasteropoda	R	5·0	0·4
Pteropoda	A	26·3	1·9
Scaphopoda	F	2·3	0·2
Pisces	F	3·2	0·2
Other remains	R	0·8	0·1
		100·0	7·3

Pelagic remains :—

Foraminifera.

Globigerina bulloides.
Gl. dubia.
Globigerinoides conglobata.
Gl. rubra.
Globigerinoides sacculifera.
Globigerinella æquilateralis.
Orbulina universa.
Globorotalia menardii.

Pteropoda.

Limacina inflata.
Creseis acicula.
Cr. virgula.
Hyalocylis striata.
Clio pyramidata.
Diacria quadridentata.
Cavolinia longirostris.
C. uncinata.
Atlanta sp.

Benthic remains :—

Foraminifera.

Haplostiche dubia.
Ammomarginulina foliacea.
Textularia goesi.
Lenticulina sp.
Elphidium jenseni.
Bulimina pupoides.
B. pyrula.
Uvigerina pygmæa.
Angulogerina carinata.

The commonest constituents are *Limacina* shells, closely followed by those of *Creseis.*

Globigerina spp. and fæcal pellets are next in order of frequency. The latter make up almost half of the finer material. Shell remains are almost all of *Venus torresiana*, with a few fragments of *Amussium* or related genus. Many of the valves show holes bored by carnivorous Gasteropoda. A species of *Cadulus* is represented among the Scaphopod remains.

Station 181 : Gulf of Aden ; depth 1982 metres ; Bigelow sample ; Globigerina ooze : mud 75·6% ; organic remains 24·4%.

Pelagic remains :—

Foraminifera.

Globigerina bulloides.
Gl. dubia.
Globigerinoides conglobata.
Gl. rubra.
Orbulina universa.
Pulleniatina obliquiloculata.
Globorotalia canariensis.
Gl. crassa.
Gl. menardii.
Gl. truncatulinoides.
Gl. tumida.

Benthic remains :—

Foraminifera.

Clavulina communis.
Pyrgo depressa.
Lagena distoma.
Planulina wuellerstorfi.

A few sponge spicules are the only other benthic remains. These and rare Radiolaria are the only siliceous structures in this deposit.

Station 183 : Gulf of Aden ; depth 1105 metres ; Bigelow sample ; calcareous green mud ; mud 93·4% ; organic remains 6·6%. The following Foraminifera were the only calcareous organisms present :

Pelagic species :—

Globigerina bulloides.
Gl. dubia.
Globigerinoides rubra.
Orbulina universa.
Pulleniatina obliquiloculata.
Globorotalia canariensis.
Gl. menardii.
Gl. tumida.

Benthic species :—

Pyrgo depressa.
Lagena marginata.
Bulimina aculeata.
Virgulina subsquamosa.
Bolivina robusta.
Uvigerina asperula.
Epistomina elegans.

A very few sponge spicules were the only siliceous remains found.

Station 184 : Gulf of Aden ; depth 1270 metres ; Bigelow and Agassiz trawl samples ; green mud bordering on Globigerina ooze ; mud 89·9% ; organic remains 10·1%.

Pelagic remains :—

Foraminifera.

Globigerina bulloides.
Gl. dubia.
Globigerinoides rubra.
Gl. sacculifera.
Orbulina universa.
Pulleniatina obliquiloculata.
Globorotalia canariensis.
Gl. crassa.
Gl. menardii.
Gl. truncatulinoides.

Pteropoda.

Cavolinia longirostris.

Benthic remains :—

Foraminifera.

Textularia flinti.
T. semialata.
Sigmoilina schlumbergeri.
Robulus sp.
Bulimina pupoides.
Gyroidina soldani.
Chilostomella ovoidea.
Anomalina balthica.
Planulina wuellerstorfi.

This deposit is from the zone of transition from the shallow water green muds to Globigerina ooze. As might be expected, the usual green mud fauna is largely missing. Mollusca are rare and other groups appear to be absent. The number of species of benthic Foraminifera, characteristic of the green mud, is much reduced, and the contained tests are largely those of pelagic species found most commonly in Globigerina ooze. In this particular deposit *Globorotalia menardii* is very abundant, being as common as the species of *Globigerina* taken together. The deposit might almost be referred to as a " *Globorotalia* mud ".

There are numerous chitinous tubes of Polychæta in this deposit each with a compacted outer layer of mud. These tubes are so numerous that they must tend to bind the deposit together into a more solid layer than would otherwise be the case.

Station 185 : Gulf of Aden ; depth 2001 metres ; Bigelow and Agassiz trawl samples ; greenish-brown calcareous mud ; mud 90·5% ; organic remains 9·5%.

Pelagic remains :—

Foraminifera.

Globigerina bulloides.
Gl. dubia.
Globigerinoides conglobata.
Gl. rubra.
Orbulina universa.
Pulleniatina obliquiloculata.
Globorotalia menardii.

Benthic remains :—

Foraminifera.

Rhabdammina abyssorum.
Rh. abyssorum var. *radiata.*
Crithionina pisum var. *hispida.*
Rhizammina indivisa.
Storthosphæra albida.
Saccammina sphærica.
Tholosina bulla.
Hyperammina friabilis.
Reophax bacillaris.
R. nodulosus.
Ammodiscus exsertus.
Am. incertus.
? *Glomospira gordialis.*
Ammolagena clavata.
Haplophragmoides subglobosum.
Cyclammina pauciloculata.
Gaudryina robusta.
Clavulina communis.
Quinqueloculina auberiana.
Q. procera.
Sigmoilina schlumbergeri.
Pyrgo anomala.
P. depressa.
P. serrata.
P. lucernula.
P. murrhina.
Planispirina sphæra.
Trochammina globigeriniformis.
Lenticulina sp.
Planularia ? *albatrossi.*

Nonion umbilicatulum. *Epistomina elegans.*
Gyroidina soldani. *Planulina ariminensis.*

This deposit contains very large numbers of *Rhabdammina abyssorum.* The residue left after washing out the mud consists almost entirely of this species (see Pl. IV, fig. 2). The deposit may be compared with that described by Schmelck (1882, p. 4) from the Arctic Ocean between Spitzbergen and Norway. This deposit, however, appears from the description to be only slightly calcareous and very clayey, being a variety of the grey clay covering the floor of the Arctic Ocean in this region.

Station 188 : Gulf of Aden ; depth 528 metres ; Agassiz trawl samples ; green mud, very poor in animal remains ; mud 97·1% ; organic remains 2·9%.

Chief components.	Frequency.	% coarse material.	% deposit.
Foraminifera	R	1·9	0·1
Corals	R	2·2	0·1
Echinodermata	R	1·2	tr.
Lamellibranchiata	C	11·8	0·3
Gasteropoda	C	18·6	0·5
Pteropoda	A	38·2	1·1
Scaphopoda	VC	12·6	0·4
Pisces	VC	11·9	0·4
Other remains	R	1·6	tr.
		100·0	2·9

Pelagic remains :—

Foraminifera.

Globigerina bulloides.
Gl. dubia.
Globigerinoides conglobata.
Gl. rubra.
Gl. sacculifera.
Orbulina universa.
Pulleniatina obliquiloculata.
Globorotalia canariensis.
Gl. menardii.

Pteropoda.

Limacina bulimoides.
L. inflata.
L. trochiformis.
Creseis acicula.
Cr. virgula.
Hyalocylis striata.
Styliola subula.
Clio pyramidata.
Diacria quadridentata.
D. trispinosa.
Cavolinia longirostris.
C. uncinata.
Atlanta sp.

Benthic remains :—

Foraminifera.

Rhabdammina abyssorum.
Rhizammina sp.
Ammolagena clavata.
Cribrostomoides bradyi.
Ammomarginulina foliacea.
Verneulina triquetra.
V. variabilis.
Clavulina parisiensis.
Massilina arenaria.
Triloculina circularis.
Pyrgo depressa.
Robulus calcar.

R. iota.
Lenticulina rotulata.
Nodosaria perversa.
Glandulina radicula.
Nonion ? exponens.
Elphidium craticulatum.
Heterostegina suborbicularis.
Bulimina affinis.
B. elongata.
B. pupoides.
B. pyrula.
B. pyrula var. *spinescens.*
Uvigerina asperula.
U. pygmœa.
Ehrenbergina pacifica.

Shells of the Pteropods, *Diacria quadridentata* and *Limacina* spp., are the commonest organic remains in the deposit.

Station 189 : Gulf of Aden ; depth 91 metres ; Priestman grab samples ; sandy green mud ; mud 71·4% ; organic remains 28·6%.

Chief components.	Frequency.	% coarse material.	% deposit.
Foraminifera	R	0·8	0·3
Polyzoa	R	0·6	0·2
Echinodermata	R	0·4	0·1
Crustacea	F	2·8	0·8
Lamellibranchiata	VC	21·9	6·3
Gasteropoda	A	53·6	15·3
Pteropoda	R	1·5	0·4
Scaphopoda	F	1·4	0·4
Pisces	R	0·4	0·1
Other remains	C	16·6	4·7
		100·0	28·6

Pelagic remains :—

Foraminifera.

Globigerina bulloides.
Gl. dubia.
Globigerinoides sacculifera.
Orbulina universa.
Globorotalia menardii.

Pteropoda.

Limacina inflata.
Clio pyramidata.
Diacria quadridentata.
Cavolinia longirostris.
C. uncinata.

Benthic remains :—

Foraminifera.

Textularia pseudocarinata.
T. rhomboidalis.
Quinqueloculina sp.
Spiroloculina depressa.
Sp. grateloupi.
Triloculina tricarinata.
Robulus echinatus.
Robulus sp.
Nodosaria subscalaris.
N. subscalaris var. *paucicostata.*
Vaginulina legumen.
Sigmoidella elegantissima.
Nonion boueanum.
Elphidium crispum.
Operculina granulosa.
Bolivina amygdalæformis.
Rotalia papillosa.
Cancris auriculus.
Amphistegina radiata.
Cibicides lobatulus.

None of the species of Foraminifera and Pteropoda are common. The Pteropoda and many of the benthic Foraminifera are worn or broken. Pelagic Foraminifera are very rare. Although a large percentage consists of molluscan remains there are very few intact shells, and these only of the smallest size. For the most part the shell fragments are small, worn and discoloured. This condition of the remains would indicate the presence of a current along the bottom here, removing the finer mud and rolling the calcareous particles about, thus gradually wearing them away. There is a small amount of H_2S in the deposit.

Station 190 : Gulf of Aden ; depth 183 metres ; Priestman grab samples ; green sand and mud ; mud 57·2% ; organic remains 42·8%.

Chief components.	Frequency.	% course material.	% deposit.
Echinodermata	F	5·0	2·2
Lamellibranchiata	A	53·6	22·9
Gasteropoda	VC	21·3	9·1
Pteropoda	VC	12·0	5·1
Scaphopoda	F	3·8	1·6
Pisces	R	1·6	0·7
Other remains	R	2·7	1·2
		100·0	42·8

Pelagic remains :—

Foraminifera.

Globigerina bulloides.
Gl. dubia.
Globigerinoides rubra.
Globigerinella æquilateralis.
Orbulina universa.
Candeina nitida.
Globorotalia canariensis.
Gl. menardii.

Pteropoda.

Clio pyramidata.
Diacria quadridentata.
Cavolinia longirostris.
Cavolinia uncinata.
Atlanta sp.

Benthic remains :—

Foraminifera.

Textularia agglutinans.
T. pseudocarinata.
Clavulina tricarinata.
Spiroloculina depressa.
Sigmoilina schlumbergeri.
Triloculina tricarinata.
Robulus acutauricularis.
Robulus sp.
Nodosaria scalaris.
Saracenaria italica.
Nonion boueanum.
Operculina granulosa.
Bulimina ovata.
B. pagoda.
Bolivina beyrichi.
B. compacta.
B. robusta.
Uvigerina pygmæa.
Valvulineria allomorphinoides.
Rotalia papillosa.
Cancris auriculus.
Cibicides lobatulus.

This deposit contains many Pteropod shells and borders on a Pteropod ooze. Corals and Polychæta are absent. Valves of *Venus torresiana* are abundant (see Pl. II, fig. 1).

Station 191 : Gulf of Aden ; depth 274 metres ; Priestman grab samples ; green mud ; mud 98·0% : organic remains 2·0%.

Chief components.	Frequency.	% coarse material.	% deposit.
Echinodermata	F	2·5	0·1
Crustacea	R	0·3	tr.
Lamellibranchiata	A	69·9	1·4
Gasteropoda	F	11·2	0·2
Pteropoda	C	10·3	0·2
Scaphopoda	F	3·8	0·1
Pisces	R	1·1	tr.
Other remains	R	0·9	tr.
		100·0	2·0

Pelagic remains :—

Foraminifera.

Globigerina bulloides.
Gl. dubia.
Globigerinoides conglobata.
Gl. rubra.
Orbulina universa.
Pulleniatina obliquiloculata.
Globorotalia canariensis.
Gl. menardii.

Pteropoda.

Limacina bulimoides.
L. inflata.
L. trochiformis.
Creseis acicula.
Cr. virgula.
Hyalocylis striata.
Clio pyramidata.
Diaeria quadridentata.
Cavolinia longirostris.
C. uncinata.
Atlanta sp.

Benthic remains :—

Foraminifera.

Textularia pseudocarinata.
Clavulina tricarinata.
Spiroloculina grateloupi.
Robulus sp.
Nonion boueanum.
N. ? exponens.
Bulimina ovata.
Bulimina pagoda.
B. pyrula.
Uvigerina brunnensis.
U. pygmæa.
Rotalia papillosa.
Chilostomella ovoidea.

Crustacean remains in the above table are chiefly the valves and compartments of various species of Cirripedia. The animal material consists mainly of the valves of *Venus torresiana.*

Station 192 : Gulf of Aden ; depth 366 metres ; Priestman grab sample ; dark green mud ; mud 97·7% ; organic remains 2·3%.

Pelagic remains :—

Globigerina bulloides.
Gl. dubia.
Globigerinella æquilateralis.
Orbulina universa.
Pulleniatina obliquiloculata.
Candeina nitida.
Globorotalia canariensis.
Gl. menardii.

Pteropoda.

Limacina inflata.
L. trochiformis.
Creseis acicula.
Cr. virgula.
Hyalocylis striata.
Clio pyramidata.
Atlanta sp.

Benthic remains :—

Foraminifera.

Reophax sp.
Textularia semialata
Triloculina trigonula.
Nonion boueanum.
Bulimina ovata.
Bulimina pyrula.
B. pyrula var. *spinescens.*
Uvigerina brunnensis.
U. pygmæa.
Cancris auriculus.

Gasteropoda.

Ranella sp.
Pleurotoma sp.

Lamellibranchiata.

Amussium sp.
Venus torresiana.

Valves of *Venus torresiana* are frequent. Small fæcal pellets are common. Pteropod shells form about 80–85% of the coarse material, *i. e.* 1·8–1·9% of the deposit, but there is insufficient sifted material available to determine the proportions more accurately.

Station 193 : Gulf of Aden ; depth 1061 metres ; Agassiz trawl sample only ; grey-green mud ; mud 58·3% ; organic remains 41·7%.

This is a sifted trawl sample consisting of clinkers and large bivalves containing mud. The above percentages are based on this contained mud. It is possible that the mud in these shells is not representative of the deposit, as they may be filled by the finest mud drifting into them through the small space between the half-open valves. The deposit might be described as Globigerina mud as it approaches a Globigerina ooze.

Pelagic remains :—

Foraminifera.

Globigerina bulloides.
Gl. dubia.
Globigerinoides rubra.
Gl. sacculifera.
Orbulina universa.
Pulleniatina obliquiloculata.
Globorotalia canariensis.
Gl. menardii.

Benthic remains :—

Foraminifera.

Spiroplectammina milletti.
Clavulina communis.
Spiroloculina grateloupi.
Sigmoilina schlumbergeri.
Robulus sp.
Dentalina filiformis.
Vaginulina legumen.
Nonion umbilicatulum.
Bulimina ovata.
Bulimina pyrula.
Uvigerina schwageri.
Rotalia papillosa.
Cancris auriculus.
Ehrenbergina pacifica.
Anomalina balthica.
Planulina ariminensis.
Laticarinina pauperata.

Only one Pteropod shell, *Clio pyramidata,* occurred in this deposit. A few Gasteropod shells and *Dentalium* sp. and Crustacean remains occur. Chelæ of a Stomatopod and of *Polycheles* sp. were found.

Station 204 : Red Sea ; depth 110 metres ; Priestman grab sample ; green Globigerina mud ; mud 81·1% ; organic remains and carbonaceous grains 18·9%.

Chief components.	Frequency.	% coarse material.	% deposit.
Foraminifera	A	84·7	16·0
Lamellibranchiata	C	11·7	2·2
Gasteropoda	R	1·3	0·2
Pteropoda	R	1·5	0·4
Other remains	R	0·8	0·1
		100·0	18·9

Pelagic remains :—

Foraminifera.

Globigerina bulloides. *Globorotalia canariensis.*
Orbulina universa. *Gl. menardii.*
Pulleniatina obliquiloculata.

Pteropoda.

Limacina bulimoides. *Clio pyramidata.*
L. inflata. *Diacria quadridentata.*
L. trochiformis. *D. trispinosa.*
Creseis acicula. *Cavolinia inflexa.*
Cr. virgula. *C. longirostris.*
Hyalocylis striata. *Atlanta* sp.

Benthic remains :—

Foraminifera.

Ammobaculites calcareum. *Nonion boueanum.*
Textularia sagittula var. *atrata.* *Bulimina pagoda.*
Clavulina tricarinata. *Uvigerina aculeata.*
Planularia tricarinella. *U. pygmæa.*
Polymorphina ? complexa.

Fragments of the Gasteropods *Ranella* and *Rostellaria* and of the Scaphopod *Cadulus* are recognizable. Larval *Triforis* shells are very common. There is much organic matter in this deposit which, with the green mineral grains, gives the deposit its colour.

Station 206 : Red Sea ; depth 256 metres ; Priestman grab samples ; green Pteropod ooze ; mud 24·7% ; organic remains 75·3%.

Chief components.	Frequency.	% coarse material.	% deposit.
Foraminifera	A	..	62·1
Echinodermata	C	6·6	0·9
Lamellibranchiata	R	3·1	0·4
Gasteropoda	F	6·7	0·9
Pteropoda	A	60·5	8·0
Pisces	C	6·4	0·8
Other remains	F	16·7	2·2
		100·0	75·3

Pelagic remains :—

Foraminifera.

Globigerina bulloides.	*Orbulina universa.*
Gl. dubia.	

Pteropoda.

Limacina helicina.	*Clio pyramidata.*
L. inflata.	*Diacria quadridentata.*
Creseis acicula.	*Cavolinia globulosa.*
Cr. virgula.	*C. longirostris.*
Hyalocylis striata.	*Atlanta* sp.

Benthic remains :—

Foraminifera.

Textularia sp.	*Rotalia papillosa.*
Bolivina amygdalæformis.	

The large percentage of " Foraminifera " in the above table is composed mainly of Foraminifera. Some primordial shells of Pteropoda and fæcal pellets are, however, included in this amount as they are not easily separated.

Almost all the groups that form calcareous skeletons are present in this deposit, but only those in the above table are present in sufficient quantity to influence the nature of the deposit.

Station 207 : Red Sea ; depth 375 metres ; Priestman grab samples ; green Pteropod ooze ; mud 65·7% ; fine organic remains 22·0% ; coarse organic remains 12·3%

Chief components.	Frequency.	% coarse material.	% deposit.
(Foraminifera)	(C)	..	(11·0)
Echinodermata	VC	12·8	1·6
Gasteropoda	F	6·3	0·8
Pteropoda	A	65·4	8·1
Pisces	VC	10·3	1·2
Other remains	R	5·2	0·6
		100·0	12·3

Pelagic remains :—

Foraminifera.

Globigerina bulloides.	*Globigerina dubia.*

Pteropoda.

Limacina inflata.	*Clio pyramidata.*
L. trochiformis.	*Diacria quadridentata.*
Creseis acicula.	*Cavolinia longirostris.*
Cr. virgula.	*C. uncinata.*
Hyalocylis striata.	

The fine organic material (22·0%) consists, approximately, half of Pteropod fragments and half of Foraminifera. Hence the total Pteropod part of the deposit is in the region of 19·1%.

This deposit is the most typical Pteropod ooze found by the expedition (see Pl. III, fig. 1).

Station 209 : Red Sea ; depth 366 metres ; coarse dredge sample only ; the deposit appears to be greenish-brown mud with rock.

Pelagic remains :—

Globigerina bulloides was the only pelagic Foraminiferan found.

Pteropoda.

Limacina inflata.	*Diacria quadridentata.*
Creseis acicula.	*Cavolinia globulosa.*
Cr. virgula.	*C. longirostris.*
Hyalocylis striata.	*C. uncinata.*
Clio pyramidata.	*Atlanta* sp.

Benthic remains :—

Only one Foraminiferan, *Rhabdammina abyssorum*, was found.

Corals.

Caryophyllia sp.	*Rhizotrochus* sp.
Flabellum sp.	

Gasteropoda.

Conus sp.	*Solarium* sp.

Fish otoliths and Echinoderm remains occur. A large part of the material preserved consists of unidentifiable calcareous rubble and rock fragments.

The following stations were carried out from the motor-boat :

Motor-boat Station I (*b*) : Red Sea ; depth 29 metres ; sand, shell and coral bottom.

The deposit is a fine sand containing fragments of most shallow-water calcareous organisms. *Alveolinella boscii* and *Ammodiscus* sp. occur among the Foraminifera present.

Motor-boat Station I (*d*) : Red Sea ; depth 26 metres ; calcareous sand.

The deposit is similar to the proceeding. Species of *Textularia* and *Robulus* are present. A few Ostracod valves occur and stray specimens of *Cavolinia longirostris* and *C. tridentata.*

Motor-boat Station II (*a*) : South Arabian Coast ; depth 11 metres ; dredge sample ; calcareous shell sand.

Large shell fragments are common. Pteropoda are rare, only *Creseis acicula* being found. The following Foraminifera occur :—

Quinqueloculina sp.	*Sorites marginalis.*
Elphidium sp.	*Peneroplis pertusus.*

Motor-boat Station II (*c*) : South Arabian Coast ; depth 29 metres ; dredge sample ; calcareous sand.

This sample is similar to the preceding, but slightly coarser. *Bolivina* sp. and *Peneroplis pertusus* were the only Foraminifera found. Fragments of Serpulid tubes and of *Balanus* spp. are present.

III. DISTRIBUTION OF THE DEPOSIT TYPES.

1. Topography.

In descriptions of the bottom configuration of the Arabian Sea various names have been proposed for the several deep areas or basins. In the present report I have adopted as a basis those proposed by Wüst (1936). He divides the Arabian Sea into two basins, a North-eastern "Arabian Basin" and a South-western "Somali Basin", separated by the Carlsberg Ridge. In the light of present knowledge of the area this subdivision of the sea-bed is insufficient. First, the discovery of the Murray Ridge parallel to the South Arabian Coast has disclosed a narrow, discontinuous deep area lying along this coast, continuous with a somewhat shallow basin at the mouth of the Gulf of Oman. For ease in the description of its deposits I propose to call this the "Oman Basin". Its south-eastern boundaries are the extension northwards of the Carlsberg Ridge, parallel to the Arabian coast, and South Bank, the most southerly of the series of ridges running in a south-westerly direction from Karachi (see Farquharson, 1936, chart ii).

Secondly, soundings have indicated the probable existence of a ridge projecting out from the African coast in lat. 4° N., running East-south-east across the Somali Basin of Wüst, and probably meeting a similar ridge running towards it in a north-westerly direction from the north side of the Saya de Malha Bank. The Somali Basin thus appears to be divided into two, and I propose here to refer to its parts as the North and South Somali Basins.

These basins are shown in Chart II, which is based on tracings of those prepared by Farquharson (1936). The basins are defined by the 1000 and 2000-fm. contours. Two slight alterations have been made in the configuration of the bottom contours as originally drawn by Farquharson. Investigation of the hydrography has shown that a connection is necessary between the North Somali Basin and the Arabian coastal portion of the Oman Basin to account for the occurrence of the bottom-water found there. In Chart II this connection is shown by uniting the closed 2000-fm. contour east of Socotra through the small 2000-fm. patch south of it, to the corresponding contour of the North Somali Basin. There are no known soundings rendering this alternative charting of the contours impossible.

A similar connection is postulated between the Chagos Archipelago and the Carlsberg Ridge, connecting the Arabian Basin and the Indian-Australian Basin. This, again, is not incompatible with our present knowledge of the soundings. The 2000-fm. contour immediately west of Owen Bank may be continued northwards across the two deep gullies to join the closed southern extremity of the same contour in the Arabian Basin. Accordingly this modification has also been made to the chart.

2. Distribution.

Our knowledge of the distribution of the deposits in the Indian Ocean previous to the "John Murray" Expedition is summed up by Murray and Philippi in their chart published in the report on the "Valdivia" deposits and in that published by Murray in the report on the "Sealark" deposits. From the limited records then available they

showed the greater part of the Arabian Sea to be covered by Globigerina ooze, with a patch of red clay in the area now termed the Arabian Basin and one of Radiolarian ooze in the South Somali Basin. A narrow belt of terrigenous muds, which is considerably wider at the northern end of the Arabian Sea, is shown extending round the coasts. Globigerina ooze is shown to extend as a continuous tongue into the Gulf of Aden, and a few isolated patches of Pteropod ooze are shown along the East African coast and in the Red Sea. Coral muds and sands are shown around all the island groups falling within our present area. No attempt was made in these earlier reports to distinguish between those areas covered by pure Globigerina ooze and those deeper areas covered by an ooze containing a proportion of red clay and brownish or fawn in colour. In the present report I have endeavoured to make such a distinction. The Globigerina ooze areas have been divided into pure Globigerina ooze (pink on chart) and "transitional" ooze (orange on chart). The latter deposit is usually distinguishable on account of its finer texture, fewer Foraminifera and greater cohesion as compared with pure Globigerina ooze. The deposit is considerably more friable than red clay. It is simply a mixture of red clay and Globigerina ooze, and its depth distribution lies between those of these two deposits.

In Chart III the distribution of the deposit-types is shown as revised from Murray's charts in the light of recent discoveries in this area. The distribution of each type is briefly described below.

(a) *Brown, green and grey muds.*—These terrigenous deposits (blue on charts) form a narrow belt along the African coast as far north as Ras Hafún. Off the Arabian and Indian coasts they form a much wider belt. This belt is considerably broader off the Arabian coast than was supposed by Murray, but is of less extent than shown by him off the coast of Baluchistan. Off the Arabian coast it extends below the 2000-fm. line and fills part of the Oman Basin. These deposits floor the Gulf of Oman except for a small patch of Pteropod ooze at its western extremity. The bottom of the Gulf of Aden and Red Sea is covered with this deposit except for small patches of other deposits.

(b) *Globigerina ooze.*—Pure Globigerina ooze (pink on charts) occurs, according to Murray, in the deep central trough of the Red Sea. In the Gulf of Aden it is not possible to lay down definite boundaries to this deposit owing to the very irregular contours of the bottom. The three patches shown on the chart are the only areas definitely known; others, however, may occur in the deep gullies between the ridges, from which we have no material.

In the open sea pure Globigerina ooze forms a belt lying below the muds, and continued along either side of the line of the Laccadive, Maldive and Chagos Archipelagos. A large patch of Globigerina ooze projects along the Carlsberg Ridge in a south-easterly direction and into the North Somali Basin. There may be a small patch separating the North and South Somali Basins. According to Wiseman and Sewell (1937, p. 222), in "the Somali Basin the sea floor is composed of globigerina ooze . . ." In this paper the transitional ooze has not been differentiated from normal Globigerina ooze, and the patch of Radiolarian ooze in the South Somali Basin has been overlooked.

There is a continuous deposit of Globigerina ooze on the bottom south of a line drawn from the south end of the Maldives to about the latitude of Mafia off the African coast. This continuous area is only broken by the coral deposits round the various archipelagos.

(c) *Transitional ooze.*—A large part of the remaining sea-bottom is covered by transitional ooze (orange on chart), intermediate in character between Globigerina ooze and

red clay. This deposit forms a belt round the central red clay areas of the Arabian, North Somali and South Somali Basins, and also covers a large area connecting these three basins to the east of the North Somali Basin. There is probably a similar belt east of the Chagos Archipelago on the edge of the Indian-Australian Basin.

(d) *Red clay.*—This deposit (brown on chart) fills the centres of the three large basins of the Arabian Sea and the Indian-Australian Basin. Its limits are somewhat doubtful in the Arabian Basin owing to the wide expanse of transitional ooze here and the very gradual transition into pure red clay. It is possible that pure red clay occupies a less area than is shown on the chart, as many of the existing records of red clay probably refer to transitional deposits. Taken at their face value these records render the areas of red clay fairly definite in the Arabian and North Somali Basins. In the South Somali Basin, however, such is not the case, and the extent of the red clay has largely to be deduced from two true red clay samples from the western side, several samples of transitional ooze, and the records of Radiolarian ooze used by Murray to determine the area of this latter deposit. Accordingly the boundary of the red clay is here drawn in to include the red clay stations, the Radiolarian ooze, and just to exclude the known areas of transitional ooze. For the rest the 2500-fm. contour has been roughly followed.

(e) *Radiolarian ooze.*—No samples of this deposit (dark brown on chart) were obtained by the expedition, and the area of this deposit has been copied direct from Murray's (1909) chart of the region.

(f) *Pteropod ooze.*—This deposit (red on chart) occurs intermittently along the African coast. Five small areas are shown by Murray along this coast and three more were found by the "John Murray" expedition. (Only seven are shown on the chart, the most southerly shown by Murray being outside the area illustrated.) All these deposits lie along the line of transition from terrigenous mud to Globigerina ooze. It is possible that there is an almost continuous belt of this deposit along this coast. Murray has recorded Pteropod ooze in the Central and Southern Red Sea, surrounded by Globigerina ooze, and at the boundary between the terrigenous mud and Globigerina ooze respectively. The expedition has shown the existence of a further patch to the south of these, just north of the "sill", that separates the Red Sea from the Gulf of Aden. A smaller and rather impure patch of Pteropod ooze was found in the Gulf of Oman. These two latter areas differ from the others in that they are entirely surrounded by terrigenous mud and are not on the edge of the Globigerina ooze. A similar patch is recorded in the "Investigator" station list (Sta. 212) from off the Gulf of Cambay. Sewell (1935*a*, pl. x) shows several patches of this ooze in the Maldive Archipelago.

(g) "*Coral*" *deposits.*—These (yellow on chart) are copied from Murray with slight alterations, where these appear necessary in the light of recent soundings, which have corrected the contours and so make it probable that the areas of coral deposits should here be curtailed. A small area of coral reefs and sand is situated on the Arabian side of the Straits of Bab el Mandeb. This area has been recorded several times by various survey ships, the soundings being published in the Admiralty "List of Oceanic Depths."

In the chart of the deposits (Chart III) the top of the Carlsberg Ridge has been represented as covered by Globigerina ooze or transitional ooze. It is possible, however, that parts at least of the ridge may be bare of deposits, as both basalt (Sta. 133) and Limestone (Sta. 168) have been obtained by dredging here on the two crossings of the ridge by the

"Mabahiss". It is also possible that the summits and troughs of the great ridge system may be covered by slightly different sediments, *e. g.* Globigerina ooze on the ridges and red clay in the troughs.

3. The Zanzibar Area (Chart IV).

For present purpose the "Zanzibar Area" is taken to include that portion of the Indian Ocean lying between Lat. 3° S. and Lat. 7° S., and bounded to the west by the African coast and to the east by the meridian 41° 4′ E. These boundaries include those stations (116–118) lying to the north of Zanzibar and the outlying station 120, as well as those between Zanzibar, Pemba and the mainland.

In determining the boundaries of the deposits the records of the "Valdivia" and those in the "List of Oceanic Depths" have been drawn upon in addition to the new records obtained by the expedition.

Along the coast there is the usual belt of green and brown terrigenous mud giving place to Globigernia ooze below about 400 fms. (738 m.). In the shallow area of the Zanzibar Channel this mud is replaced by a deposit of sand and gravel formed of the calcareous remains of organisms (shells, coral, coralline algæ, Polyzoa, etc.) and the massive tests of bottom-living Foraminifera. These materials are undoubtedly derived in great part from the coral reefs with which the channel is said to be fringed on either side. Another much smaller sand area occurs on the mainland coast to the west of Pemba Island. At the north end of Zanzibar Island is an area of sand and coral. There is another record of coral south-west of Zanzibar and a third south-east of the island on the 7° S. parallel. These records are those of cable-ships and others and hence cannot be relied upon to mean *Madreporarian* coral, though they may do so as coral is common in shallow water in this region. *Lithothamnion* and other coralline algæ are classed as "coral" for purposes of a marine survey of the bottom. A number of records show coral patches to occur in a more or less continuous series along the coast north of Pemba as far as Mombasa. These are apparently part of a more or less continuous reef running along this coast from Zanzibar northwards, and perhaps interrupted at intervals where rivers enter the sea or conditions are otherwise unfavourable for the growth of coral. Fewer records of this coral are available along the mainland coast inside of Pemba and Zanzibar, as this coast has not been worked in the same detail as farther north, where the records lie along the track of a submarine cable. The 'Admiralty Pilot' (p. 321) states that reefs lie along both sides of this channel. Crossland (1902, p. 501) states that coral occurs around all the sand flats off the west coast of Zanzibar Island. Coral was found by the Expedition at Sta. 112 on the African coast and also at an anchorage (Port George) on the Pemba coast. It may therefore be assumed that there is a roughly continuous reef along this part of the coast also.

Terrigenous mud surrounds Pemba Island but only occurs on the seaward side of Zanzibar. To the south of Zanzibar it apparently gives place entirely to sand for a short distance, the sand merging directly into Globigerina ooze in deep water. This phenomenon is probably due to the current, produced by the flow of water into the Zanzibar Channel, sweeping mud away from the region of Ras Kimbiji. The remainder of the Zanzibar Area is covered by Globigerina ooze except for two small patches of Pteropod ooze. As mentioned above, these occur between the terrigenous mud and Globigerina ooze. One lies south-east of Zanzibar in 200 fms. (369 m.) and the other west of Sta. 117 in 400 fms. (738 m.).

Globigerina ooze extends in an impure form, mixed with terrigenous mud, into the deep-water channel west of Pemba Island. It is of interest to note that the area of Globigerina ooze does not correspond exactly with the contours of the channel as outlined by the 400-fm. line. It lies throughout somewhat to the westward and extends in one place above 200 fms. On its eastern side it gives place to terrigenous mud in the deep part of the channel. At its northern extremity this tongue of Globigerina mud, as it has now become, lies entirely to the westward of the 400-fm. contour and extends into shallow water, where it merges with the sand-shell area in about 200 fms.

According to the 'Pilot' (p. 369), the current sets constantly to the northward in the northern part of the Pemba Channel. It is a branch of the main northerly current which is divided by Ras Upembe, the southernmost point of Pemba Island. This northerly current is itself part of the south equatorial current, deflected northwards near the coast. The current is said to follow the axis of the channel. This is apparently the agent transporting the Globigerina ooze into the Pemba Channel. In the northern part of the channel this current is sometimes overcome by the flood setting southward near the Pemba coast. This counter-current may be sufficient to force the northerly stream to the westward of its course, and to slow it up so that it drops its load here to the westward of the deep part of the channel. At the same time the southerly current would itself lose speed, which probably accounts in part for the large deposit of mud on the west side of Pemba Island. Difficulty in getting the trawl on the bottom was experienced at two stations, 121 and 124, in the channel between Pemba Island and Zanzibar Island, the wire streaming out at an angle of 45° to the horizontal. This appeared to be due to a considerable current flowing in a north-north-westerly direction through the channel between the islands at a depth of about 750 m., *i.e.* near the bottom. Doubtless this current also helps to carry the components of Globigerina ooze into the Pemba Channel.

Alternatively, the region being south of the equator, the currents tend to swing to the left owing to the spin of the earth, and this may be the reason for the deposition of Globigerina ooze to the westward of the deep part of the channel.

IV. BIOLOGICAL COMPOSITION OF THE DIFFERENT TYPES OF DEPOSIT.

1. General.

The biological components of the deep-water marine deposits collected consist mainly of the remains of Mollusca, Echinodermata and Foraminifera, together with small quantities of the remains of other animals, notably Polyzoa and Fish. Radiolaria and Diatoms are rare. Only the Foraminifera have been identified in any detail. The pelagic species found in the deposits are a true part of the sediment, as only the dead shells are found there. The bottom-living forms that have been identified are in many cases represented by the tests of animals that were living at the time the material was obtained, and thus are not strictly part of the deposit but belong to the fauna. The tests of dead individuals, however, contribute to the deposit, so these " living " Foraminifera have been included among the biological components of the sediments. Many species are locally abundant, and are of considerable importance as components of the sediment both in determining the consistency of the deposit and as a possible source of food for higher animals. The lists

of Foraminifera included in this section are not exhaustive, but are given in order to differentiate the several deposit-types.

The following list indicates the stations from which material of each of the seven deposit-types was obtained :

a. Grey clay and mud.
  Stas. 26, 38, 39, 63, 64, 76, 81, 85, 88, 109, 125.

b. Green and brown muds.
  Stas. 5, 14–18, 20, 21, 29, 32–35, 50, 54-59, 65, 66, 70, 73, 74, 79, 104–106, 108, 110, 117, 122, 123, 126, 175, 176, 179a, 179b, 180, 183–185, 188, 189, 191–193, 204.

c. Coarse deposits.
  Sands: Stas. 24, 27, 53, 80, 89, 103, 112, 113, 178.
  Rock: Stas. 42, 209.
  Conglomerate: Stas. 6, 45, 72, 111.

d. Globigerina ooze.
  Stas. 22, 60, 62, 87, 93, 102, 114, 118–121, 135, 156, 170, 173, 181.

e. Transitional ooze.
  Stas. 92, 127, 128, 132, 134, 167.

f. Pteropod ooze.
  Stas. 7, 28, 67, 75, 77, 190, 206, 207.

g. Red clay.
  Stas. 100, 101, 166.

h. Deposits from the Maldive Archipelago.
  Stas. 137, 139, 141, 142a, 142b, 143–145, 147, 149, 151, 152, 157–161, 163–165.

2. Biological Composition of the Deposits.

(a) *Grey Mud and Clay.*

With the exception of two samples, one of mud and one of clay, from the Zanzibar region, all the materials come from the coastal region stretching from the Gulf of Aden to Karachi and down the west coast of India as far as Bombay. In this area seven samples of grey mud and three of grey clay were collected. The grey muds for the most part occur in deep water, ranging, with the exception of the sample from off Zanzibar in 640 m., from 1687 m. to 3556 m. The average depth is 3135 m. The grey clays vary in depth from 274 m. to 1703 m., the average depth being 867 m. The actual percentage of animal remains in the two deposits is very similar, averaging about 6·3% by weight of the deposit for all the samples and varying from 3·7% to 12·7%, with one extreme case of a grey mud in which no remains were found. The average is slightly higher in the clays than in the muds. The washed clay from Sta. 88 leaves a residue very similar to Pteropod ooze, being composed mainly of Pteropod shells. As, however, these only form 0·6% of the deposit (but 33·3% of the animal remains), the deposit cannot be classed as a Pteropod ooze. A typical sample of the animal remains present in grey mud is shown on Pl. I, fig. 1.

The two types of deposit are difficult to separate, the chief difference being the greater cohesive power of the clay as compared with the mud and the smaller number of species whose remains occur in the clay. The following comparative lists show the paucity of species in the grey clay as contrasted with the grey mud :

Grey mud.	Grey clay.
Pelagic remains :—	
Foraminifera.	
Globigerina bulloides.	*Globigerina bulloides.*
Gl. dubia.	*Gl. dubia.*
Globigerinoides conglobata.	*Globigerinoides rubra.*
Gl. rubra.	*Gl. sacculifera.*
Gl. sacculifera.	*Orbulina universa.*
Globigerinella æquilateralis.	*Globorotalia menardii.*
Orbulina universa.	
Pulleniatina obliquiloculata.	
Globorotalia menardii.	
Pteropoda.	
Limacina inflata.	*Limacina inflata.*
Clio pyramidata.	*Creseis acicula.*
Cuvierina columnella.	*Cr. virgula.*
Diacria quadridentata.	*Hyalocylis striata.*
D. trispinosa.	*Diacria quadridentata.*
Cavolinia longirostris.	*Cavolinia longirostris.*
Atlanta sp.	*C. uncinata.*
	Atlanta sp.
Other remains.	
Otoliths, scales.	Fish vertebræ.
Coscinodiscus sp.	
Radiolaria, incl. *Lithocircus* sp.	
Benthic remains :—	
Foraminifera.	
Rhabdammina abyssorum.	*Quinqueloculina* sp.
Rh. discreta.	*Triloculina* sp.
Rh. linearis.	*Robulus acutauricularis.*
Crithionina pisum.	*Bulimina elongata.*
Cr. pisum var. *hispida.*	*B. ovata.*
**Marsipella cylindrica.*	*B. pyrula.*
Storthosphæra albida.	*Uvigerina bifurcata.*
**Pilulina jeffreysi.*	*U. pygmæa.*
**Hyperammina elongata.*	
H. friabilis.	
**H. lævigata.*	
**Reophax pilulifer.*	
**Hormosina carpenteri.*	
**H. globulifera.*	
Haplophragmoides subglobosum.	
**Clavulina communis* var. *nodulosa.*	
Pyrgo depressa.	

* These species were found in grey mud only.

Grey mud.	Grey clay.
P. murrhina.	
**Lenticulina reniformis.*	
Amphisorus hemprichi.	
Nonion umbilicatulum.	
Bulimina aculeata.	
B. pyrula.	
Gyroidina soldani.	
Rotalia beccarii.	
Epistomina elegans.	
Planulina wuellerstorfi.	
Cibicides lobatulus.	
Other remains.	
Polychæt, Echinoderm, Gasteropod, Lamellibranch, Scaphopod fragments.	Small Gasteropoda. Small Lamellibranchiata.
Ostracod valves.	
Poriferan spicules.	

NOTE.—In the above list the Foraminifera from Sta. 125 (grey clay from off Zanzibar) are omitted.

It is noticeable that the pelagic remains are very similar in both grey muds and clays. This is to be expected, as the pelagic fauna is not affected by the type of bottom. The difference between the two types of deposit is shown somewhat strikingly by the micro-fauna of the bottom. Grey clay supports an extremely small number of animals restricted to very few species, and many groups are entirely lacking in the material examined. The less clayey muds, on the other hand, support quite a rich Foraminiferal fauna, and representatives of most of the bottom-living groups of organisms are present.

The grey muds appear to be mixtures of grey clay (probably of terrigenous origin and a shallow-water deposit), with either green or brown terrigenous mud or Globigerina ooze. The former type is shown by the shallow-water muds from 640 m. off Zanzibar and 1687 m. off Bombay. The rest, from depths from 2156 to 3556 m., are evidently on the borders of the Globigerina ooze and for the most part are grey or fawn-white in colour. The Foraminiferal fauna of the deeper samples, however, shows only a few of the forms typical of Globigerina ooze. Many more arenaceous forms are present, and the fauna is quite distinct from either that of Globigerina ooze or green mud.

The grey mud from Sta. 109 (640 m.) and grey clay from Sta. 125 (805 m.) off Zanzibar are strikingly different from the other deposits of this type as regards their organic remains. The grey mud is almost devoid of organic remains, only three species of Foraminifera being identified, whereas at Sta. 125 the grey clay yielded a large number of species. This is exactly opposite to what we find in the northern Arabian sea, where the muds all contain remains of more species than the clays.

From a comparison of the faunas, the deposit at Sta. 125 resembles a grey or even a green mud far more than it does the clays from the northern Arabian Sea. Similarly the mud from Sta. 109 compares readily with the clays from this area. The numbers of

species of Foraminifera and Pteropoda present in these two samples are compared with normal grey mud and clay in Table II :—

TABLE II.

Station and deposit.	Pelagic Foraminifera.	Benthic Foraminifera.	Pteropoda.
109 ; grey mud	..	3	3
125 ; grey clay	8	39	2
Normal grey mud	9	28	6
Normal grey clay	6	8	7

Here, however, the resemblances end. The deposit at Sta. 109 is a typical mud from shallow water and is not more coherent than other inshore grey muds. That from Sta. 125, despite its faunal resemblances to a mud, is a very coherent, plastic deposit—an unmistakable clay.

These differences in the faunas of these deposits would indicate that some other factor, and not the character of the deposit alone, is responsible for the poor fauna met with in the grey clay area of the northern region of the Arabian Sea. This factor is apparently hydrological. It will be shown later (p. 148) that the water in the Gulf of Oman is very poorly oxygenated down to a depth of about 1500 m., and that the water flowing out of the Persian Gulf is highly saline. The combination of these two factors appears to kill off any animals brought into the Gulf by inflowing Arabian Sea water and permits only a limited production of life within its own confines. Where this highly saline water comes into contact with the bottom on the Arabian coast about Ras al Hadd there is a very great destruction of life, so that a large amount of organic matter accumulates in the mud. The decay of this material apparently brings about anaërobic conditions, and the bacterial production of sulphuretted hydrogen in the mud. The area about Ras al Hadd is thus rendered azoic. Further eastward there is no production of sulphuretted hydrogen in the mud, which here contains less organic matter, but the oxygen content of the water is probably so low that life cannot persist. Thus a large area of the sea-bed in the mouth of the Gulf of Oman and in the northern part of the Arabian Sea is rendered practically azoic.

(b) *Green and Brown Muds.*

Fifty samples of terrigenous mud were collected. With one exception they range in colour from dark brown to dark green. The exception (from Sta. 5) is a very light brown or yellow mud. Blue mud was not met with in the north-west area of the Indian Ocean, though the " Valdivia " obtained it three times on the East African coast and once in the Bay of Bengal (Murray and Philippi, 1908, p. 153). The range in depth at which these muds occur is considerable, samples being collected from 91 m. and 2072 m. The former is transitional to the sandy shallow-water deposits and the latter approximates to a Globigerina ooze. The average depth of the deposit is 793 m. With the exception of seven samples the percentage of animal remains is low, averaging 9·3%. The seven exceptions are tabulated below (Table III), with remarks as to the possible reason for the large amount of animal material present. They are not typical green or brown muds.

Table III.

Station	Depth (m.)	% animal remains.	Remarks.
29	2072	34·5	Transitional to Globigerina ooze ; mainly Foraminifera.
35	441	31·4	
50	1738	32·4	Sandy mud.
73	91	64·5	Very sandy mud.
110	329	62·1	Transitional to Globigerina ooze.
176	695	55·4	Largely fæcal pellets.
193	1061	41·7	A partially sifted deposit.

The more usual percentages are shown in Table IV. These have not been selected, but taken half from the top and half from the bottom of a list arranged in order of stations. In the normal muds the percentage of animal remains varies from 1·9% to 24·1%, usually between 6% and 14%. The graph (Fig. 1) shows the average percentage of animal remains per 100 m. depth. It is seen that the shallow-water deposits contain a rather high percentage, nearly 25%, which falls off very rapidly on descending into deeper water.

Table IV.

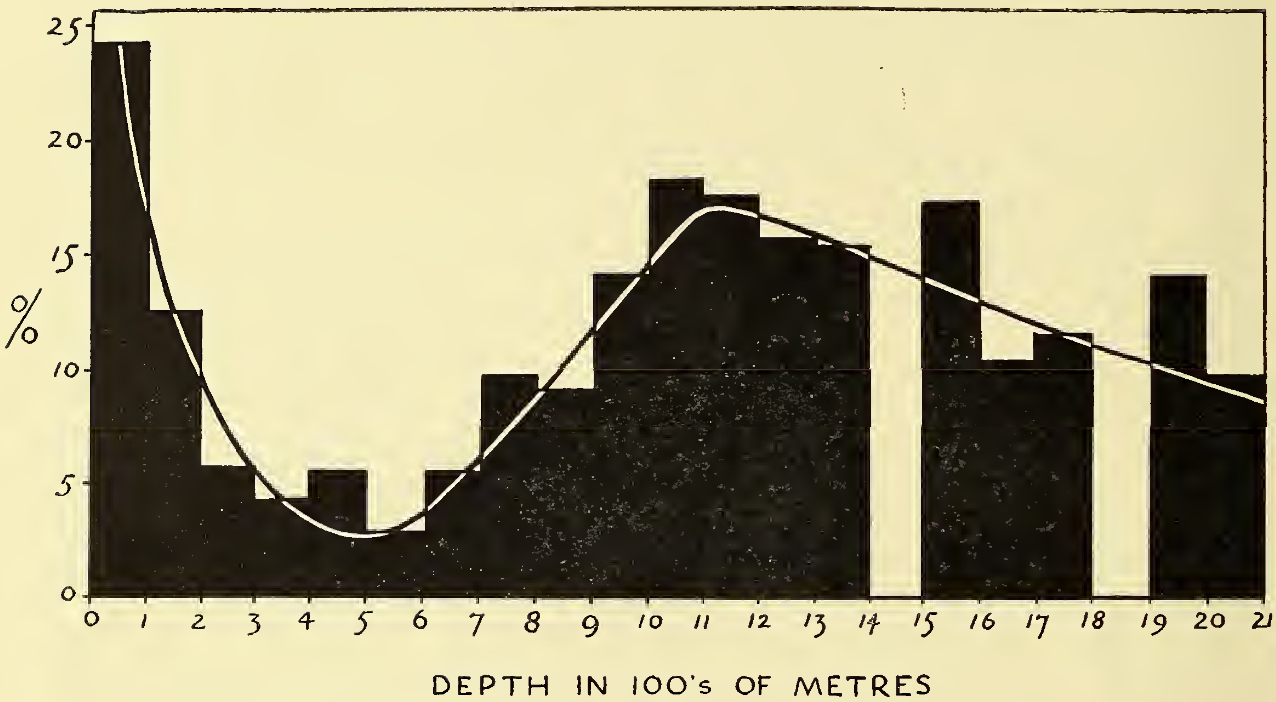
Station.	Depth (m.)	% animal remains.
5	938	14·1
14	1764	11·3
15	1053	16·8
15–16	..	9·6
16	186	11·6
179a	310	6·7
179b	275	7·8
180	397	7·3
183	1105	6·6
184	1270	10·1
	Average	10·2

A minimum percentage of animal remains is found between 500 m. and 600 m., below which depth the percentage rises again. This minimum probably marks the lower limit of the shallow-water or littoral forms and the beginning of the continental slope fauna, the two faunas exhibiting an "overlap" region in which neither is particularly abundant. Below 600 m. the amount of remains present increases considerably, to reach a maximum in about 1100–1200 m. Here the remains consist mainly of continental slope forms, plus gradually increasing amounts of pelagic material.

The shape of the curve must be influenced to a considerable degree by the amount of deposition of sediments derived from the land. In shallow water there is an abundant fauna leaving calcareous remains and, owing to constant movement of the water, little sedimentation of fine material. The percentage of animal remains in the deposit is therefore high. In rather deeper water the terrigenous material begins to be deposited and the percentage of remains falls correspondingly. This presumably goes on until about 500 m., at

which depth the maximum amount of mud is being deposited and so the percentage of remains is at a minimum. This zone of maximum sedimentation has been called by Murray the " mudline ", and is considered by him to be the richest feeding-ground of the ocean. The depth of the " mudline " naturally varies with local conditions ; 500 m. is only an average figure for the whole of the Arabian Sea. In still deeper water less and less mud is deposited, and the percentage of remains increases again to a maximum in 1100 m. This is, of course, assuming that the density of the fauna is the same throughout the depth-range (1200 m.) under consideration.

Actually both factors, namely the degree of sedimentation and the density of the fauna, probably combine to determine the shape of the curve. As is shown later (Text-fig. 2, p. 120), and as Alcock (1890, p. 426) has shown, there is a region in which life is somewhat scarce.



Text-fig. 1.—Percentage of animal remains in green mud at different depths.

The position of this region seems to vary in different areas. The " Murray " Expedition records point to a zone between about 80 m. and 150 m. as the poor area in the Arabian Sea ; Alcock gives 37–74 m. for the corresponding zone off the Ganjam coast. Thus the small amount of animal remains present in the deposit in about 500 m. may be said to be due to the poorness of the fauna in the zone above (the remains will tend to be carried into deeper water), and to the greater deposition of mud in this depth compared with shallower or deeper water.

From 1200 m. down to 2000 m. there is a fairly steady decrease in the amount of animal material and a corresponding increase in the fineness of the deposit. Finally at this lower depth the muds mostly pass into Globigerina ooze and the percentage of animal material soars again, but now consists of a high percentage of pelagic remains and very few benthic forms.

Under different conditions the depth at which the change-over from one type of

deposit to the next occurs naturally varies, and so some samples of mud contain amounts of remains abnormal for the depth. A number of such (high) values have been listed above (Table III, p. 113); exceptionally low values also occur. In averaging the percentage over each 100 m. these abnormally high values have been omitted. Similar considerations probably account for the high average values met with from 1500–1600 m. and 1900–2000 m., as shown in Text-fig. 1.

There is a further possible explanation of the minimum value for the amount of animal material at about 600 m., namely the destructive activity of the mud-feeding organisms, which may destroy large numbers of the contained small animals, chiefly Foraminifera.

The biological components of the mud fall into two groups—(i) the remains of pelagic organisms and (ii) those of benthic animals. The former are somewhat limited in number of species, probably owing to the few species of pelagic animals, in comparison with benthic animals, that leave calcareous or other resistant remains, and also to the smaller number of pelagic species in inshore waters as compared with the open ocean. The actual percentage of pelagic remains, though not calculated separately, is small, owing to swamping by the large numbers of benthic organisms, especially Foraminifera, which abound in the terrigenous muds. The following is a list of the pelagic organisms present in the muds examined:—

Foraminifera.

Globigerina bulloides.
Gl. dubia.
Globigerinoides conglobata.
Gl. rubra.
Gl. sacculifera.
Globigerinella æquilateralis.
Hastigerina pelagica.
Orbulina universa.
Pulleniatina obliquiloculata.
Sphæroidinella dehiscens.
Candeina nitida.
Globorotalia canariensis.
Gl. crassa.
Gl. menardii.
Gl. tumida.

Pteropoda.

Peraclis bispinosa.
Limacina bulimoides.
L. inflata.
L. trochiformis.
Creseis acicula.
Cr. virgula.
Hyalocylis striata.
Styliola subula.
Clio pyramidata.
Cuvierina columnella.
Diacria quadridentata.
D. trispinosa.
Cavolina inflexa.
C. longirostris.
C. tridentata.
C. uncinata.
Atlanta sp.

Other remains: Otoliths, scales and vertebræ of fish.

The pelagic components are thus similar to those of other sediments, but are richer in species, especially of Pteropoda. This abundance of Pteropoda is to be expected as the range of Pteropod ooze falls within that of the muds and in places, e. g. off the African coast and at the southern end of the Red Sea, the green muds grade into Pteropod deposits.

As already mentioned, the number of species of benthic Foraminifera is high in the green and brown muds: 192 species and varieties have been identified in these deposits: of these very few are of frequent occurrence, while a very large number were found only in three or less of the fifty samples examined. Only eighteen species occurred in five or more

samples. The following list indicates the species found and the number of times they occurred. *Bulimina pyrula* (12 stations), *Uvigerina pygmæa* (11 stations), and *Cancris auriculus* (10 stations) occur most frequently.

TABLE V.

Species.	Number of occurrences.	Species.	Number of occurences.
Rhabdammina abyssorum	3	**Verneulina scabra*	1
Rh. abyssorum var. *radiata*	1	*V. triquetra*	1
Crithionina pisum var. *hispida*	2	**V. variabilis*	1
Rhizammina indivisa	1	*Gaudryina baccata*	1
Storthosphæra albida	2	**G. pseudo-filiformis*	1
Saccammina sphærica	1	**G. robusta*	1
Pilulina jeffreysi	2	**Valvulina conica*	1
**Tholosina bulla*	2	* *V. fusca*	1
Hyperammina friabilis	1	*Clavulina angularis*	1
**Dendrophrya ramosa*	1	*Cl. communis*	6
**Reophax agglutinans*	1	*Cl. pacifica*	1
**R. bacillaris*	1	*Cl. parisiensis*	3
**R. bilocularis*	1	*Cl. tricarinata*	2
**R. guttifer*	1	**Quinqueloculina auberiana*	1
**R. nodulosus*	2	**Q. procera*	1
Haplostiche dubia	2	**Massilina arenaria*	3
**Ammodiscus exsertus*	1	*M. australis*	1
**Am. incertus*	2	*Spiroloculina depressa*	4
**Ammodiscoides turbinatus*	1	*Sp. grateloupi*	3
**Tolypammina vagans*	2	**Sigmoilina edwardsi*	1
**Ammolagena clavata*	4	*S. schlumbergeri*	8
Haplophragmoides subglobosum	2	**Triloculina circularis*	1
Cribrostomoides bradyi	1	*Tr. tricarinata*	1
**Ammomarginulina foliacea*	2	*Tr. trigonula*	1
**Cyclammina pauciloculata*	1	*Pyrgo anomala*	1
Ammobaculites calcareum	3	**P. comata*	2
Spiroplectammina milletti	4	*P. denticulata*	1
Textularia agglutinans	2	*P. depressa*	4
T. conica	2	*P. lucernula*	1
**T. goesi*	1	*P. murrhina*	5
T. gramen	3	*P. sarsi*	2
T. pseudocarinata	3	*P. serrata*	1
T. rhomboidalis	1	*P. vespertilio*	1
T. sagittula	4	*Biloculinella globula*	2
T. sagittula var. *atrata*	2	*Cornuspira carinata*	1
T. sagittula var. *fistulosa*	1	**Ophthalmidium inconstans*	1
**T. semialata*	3	*Planispirina sphæra*	2
Verneulina propinqua	1	**Trochammina globigeriniformis*	1

* These species were found only in terrigenous mud.

Species.	Number of occurrences.	Species.	Number of occurrences.
**Tr. squamata*	1	**Nonionella* sp.	1
Placopsilina cenomana	1	*Elphidium craticulatum*	1
Robulus calcar	3	*El. crispum*	3
R. costatus	2	**El. jenseni*	1
R. costatus var. multicostatus	2	*Operculina granulosa*	5
**R. echinatus*	2	*Heterostegina depressa*	3
R. gibbus	1	*H. operculinoides*	2
**R. iota*	4	*H. suborbicularis*	2
**R. limbosus*	1	*Sorites marginalis*	1
R. orbicularis	2	*Amphisorus hemprichi*	1
**Lenticulina calcarata*	1	*Marginopora vertebralis*	1
L. rotulata	4	*Bulimina aculeata*	4
**Planularia ? albatrossi*	1	**B. affinis*	1
**Pl. tricarinella*	2	**B. elegans*	1
Marginulina glabra	1	*B. elongata*	1
**Dentalina communis*	1	*B. ovata*	9
**D. consobrina*	1	*B. pagoda*	2
D. consobrina var. *emaciata*	1	**B. pupoides*	7
D. filiformis	1	*B. pyrula*	12
**Nodosaria flinti*	2	**B. pyrula* var. *spinescens*	2
N. pauciloculata	1	**B. subornata*	3
**N. perversa*	1	**Virgulina squamosa*	1
N. pyrula	1	*V. subsquamosa*	3
**N. radicula*	1	*Bolivina amygdalæformis*	2
N. scalaris	1	*B. beyrichi*	2
**N. soluta*	1	*B. beyrichi* var. *alata*	1
N. subscalaris	2	*B. dilatata*	1
N. subscalaris var. *paucicostata*	1	**B. pygmæa*	2
N. vertebralis	1	*B. robusta*	1
Saracenaria italica	1	*B. simpsoni*	1
Vaginulina legumen	2	*Uvigerina aculeata*	2
V. linearis	1	**U. asperula*	2
**V. wetherellii*	1	*U. bifurcata*	2
**Frondicularia plicata*	1	*U. brunnensis*	6
**Lagena marginata*	2	**U. proboscidea*	1
**Glandulina radicula*	1	*U. pygmæa*	11
Sigmoidella elegantissima	1	*U. schwageri*	4
**Polymorphina ? complexa*	1	*U. tenuistriata*	4
Nonion boueanun	4	**Siphogenerina bifrons*	1
**N. exponens*	2	**S. dimorpha*	1
**N. pacificum*	1	*S. striata* var. *curta*	2
**N. pompilioides*	2	**S. virgula*	1
N. scaphum	1	*Angulogerina carinata*	3
N. umbilicatulum	5	**An. carinata* var. *bradyana*	1

Species.	Number of occurrences.	Species.	Number of occurrences.
**Valvulineria allomorphinoides*	2	**Anomalina balthica*	4
Gyroidina soldani	3	**Planulina ammonoides*	1
Eponides præcinctus	2	*Pl. ariminensis*	5
Rotalia beccarii	1	*Pl. wuellerstorfi*	8
R. calcar	1	*Laticarinina pauperata*	2
R. margaritifera	2	*Cibicides lobatulus*	6
R. papillosa	7	*Planorbulinella larvata*	1
Epistomina elegans	5	*Gypsina globulus*	1
Cancris auriculus	10	*Carpenteria monticularis*	1
Amphistegina radiata	5	*C. proteiformis*	2
Cymbaloporetta bradyi	1	*C. utricularis*	1
Cymbaloporella tabellæformis	1	*Homotrema rubrum*	1
Ehrenbergina pacifica	7	*Sporadotrema cylindricum*	1
Chilostomella ovoidea	4	*Sp. mesentericum*	1
**Sphæroidina bulloides*	1	*Miniacina miniacea*	1

In addition to the above the following were identified :

Crustacea.
- *Balanus* sp.
- *Verruca* sp.

Gasteropoda.
- *Pleurotoma* sp.
- *Ranella* sp.
- *Rostellaria* sp.
- *Triforis* sp. (larval shells).

Scaphopoda.
- *Cadulus* sp.
- *Dentalium* sp.

Lamellibranchiata.
- *Amussium* sp.

Polyzoa.
- *Cellaria* sp.

Cœlenterata.
- *Acropora* sp.
- *Cycloseris* sp.
- *Pachyseris* sp.
- *Tubipora* sp.

- Hydrocorallinæ.
- Alcyonaria.

All the Cœlenterate remains come from Sta. 126.

It thus appears that the green muds are not well characterized by the presence of any typical series of species of Foraminifera ; it is, however, possible to pick out a number of genera that are represented by many species. These genera are evidently the best suited to this type of deposit and have developed many species here, but they are by no means confined to these deposits, being represented by the same or other species in very different sediments. Of such genera in the above list may be mentioned *Textularia* (8 spp. and 2 varieties), *Pyrgo* (9 spp.), *Robulus* (7 spp. identified, several unidentified), *Nodosaria* (incl. *Dentalina,* 12 spp. and 2 varieties), *Bulimina* (9 spp., 1 variety), *Bolivina* (6 spp., 1 variety) and *Uvigerina* (8 spp.). The family Buliminidæ as a whole appears to favour green or brown muds as a habitat ; many more species of this family were found in this type of deposit than elsewhere. As is to be expected, families of attached forms, like the Rupertiidæ and Homotremidæ, are rare, this type of sediment offering few or no solid objects for attachment. The species of *Carpenteria* (Rupertiidæ), *Homotrema, Sporadotrema* and *Miniacina* (Homotremidæ) found elsewhere occurred here only once or twice and

chiefly at Sta. 126 off Zanzibar Island, where the sediment is coarser than is usual for green mud.

Although the majority of the Foraminifera occur infrequently, some may be extraordinarily abundant over small areas, in which they form the bulk of the larger components of the deposit. Two such instances may be cited here. At Sta. 185, in the Gulf of Aden, the residue obtained by sifting the deposit consists almost entirely of the brown tests of *Rhabdammina abyssorum* M. Sars (see Pl. IV, fig. 2). Schmelck (1882, p. 43) records a similar abundance of this species in the Norwegian Sea under the name " Rhabdammina Clay " or " Green Clay ". This deposit was a gritty mud with quartz grains and was only slightly coherent when dry—scarcely a clay. The contained animal remains were Annelid tubes, exclusively *Spirochetopterus* sp., sponge spicules and shells of *Astarte* sp. besides *Rhabdammina*, " . . . which would appear to be comparatively numerous " (*loc. cit.*, p. 44). This composition is very similar to that of the present sample, except that here the mud is finer and with less quartz grains. Flexible worm-tubes and shell fragments are fairly common, and a few other animal remains occur but are largely obscured by the enormous numbers of *Rhabdammina*. Agassiz (1892, p. 11), again, records similar masses of a species of *Rhabdammina*, " closely allied to *R. lineata* ", from off the west coast of tropical America.

The second example is from Sta. 105, off Zanzibar. Here a large part of the residue from the sifted sediment consists of fragments of the branched Foraminiferan *Dendrophrya ramosa* Cushman (see Pl. IV, fig. 1). The deposit is again associated with a large number of fine papery worm-tubes with an adherent outer coating of mud. The probable cause of this great abundance of a bottom species in a small area is referred to elsewhere (p. 156).

Typical samples of the organic remains found in green and brown muds are shown in Pl. I, figs. 2–6, and Pl. II, fig. 1.

At Sta. 55, off Ras al Hadd, the deposit is green mud containing very large numbers of a large round diatom, *Coscinodiscus oculis-iridis* var. *borealis* (Bail.) Cl.* (see Pl. I, figs. 5, 6). This diatom also occurred in the sediments collected at the adjacent stations 56 and 57 but in far fewer numbers. Elsewhere *Coscinodiscus* spp. were absent, or represented by very rare fragments only.

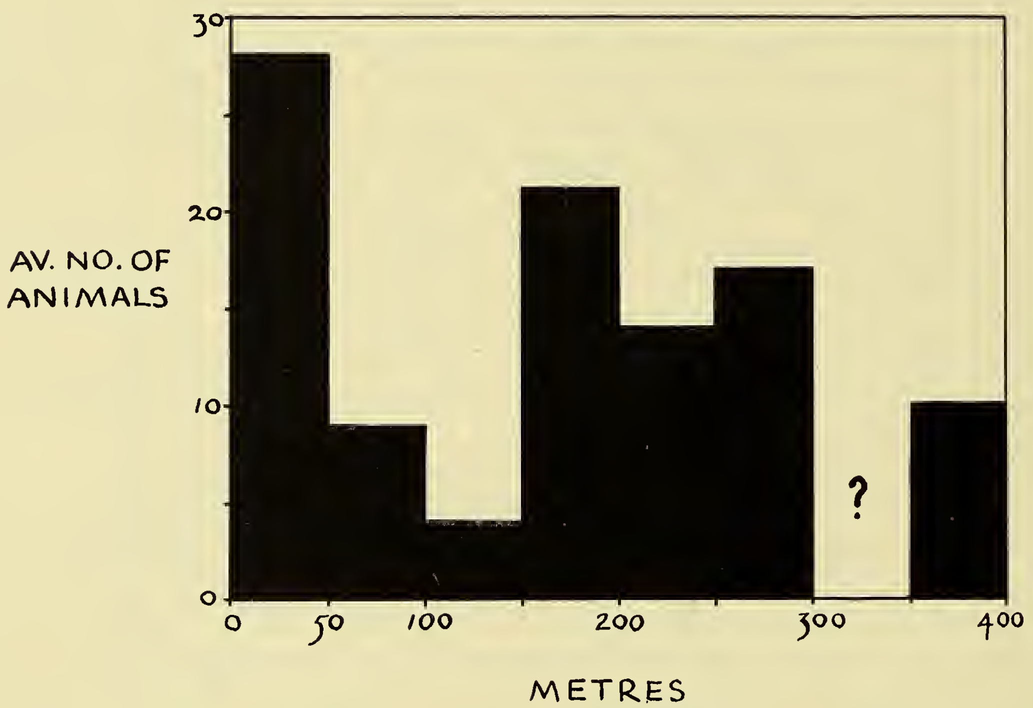
Diatom ooze is well known from the Southern Ocean and from the North Pacific, where large well-defined belts of the deposit occur. It is not common, however, in lower latitudes, and has been recorded from a relatively few isolated areas. One such area is recorded by Murray and Lee (1909, p. 48, and map ii) from off Lima, Peru, and another by Murray and Philippi (1908, chart ii) from the Southern Indian Ocean midway between Madagascar and Kerguelen in about Lat. 38° S. Both these deposits contain *Coscinodiscus* spp. Hanzawa (1935, pp. 37 *et seq.*, pls.; I, II) describes a number of Diatom oozes forming isolated patches within the area Lat. 19° 8·5′ N. to 8° 40′ N. and Long. 136° 32·6′ E. to 153° 6·5′ E. These last deposits, however, differ in that the predominating diatom is *Ethmodiscus* sp., a form similar to *Coscinodiscus*, which is here rare or absent. Thus, in the Pacific, the Diatom ooze north of the equator in low latitudes is an *Ethmodiscus* ooze and south of the equator a *Coscinodiscus* ooze, as far as one can tell from the single record known. In the Indian Ocean, however, this is not so. Here there is no northern belt of Diatom ooze, as the sea is bounded by the continent of Asia in quite low latitudes. True Diatom ooze is apparently not developed in the Indian Ocean, but deposits rich in diatoms occur off the eastern point of Arabia and in a few other areas, *e. g.* Sta. 22 in the Gulf of

* I am indebted to Dr. S. Chaffers for this identification.

Aden. This deposit off Ras al Hadd lies in Lat. 22° N., only slightly further north than the *Ethmodiscus* deposits of the Pacific, but this genus is apparently absent. *Ethmodiscus* is not recorded by Hornell and Nayudu (1924, p. 149) or Menon (1931, p. 495) from the coasts of Peninsular India. They, however, found *Coscinodiscus* to be one of the chief components of the Diatom plankton. Apparently, therefore, *Ethmodiscus* is rare in, if not absent from, the northern part of the Indian Ocean, its place being taken by species of *Coscinodiscus*.

(b. i) *The effect of depth upon the fauna on green and brown muds.*—The large number of samples (34) of terrigenous mud collected with the Priestman grab have made it possible to study the effect of depth upon the density of the macro-fauna.

The numbers of animals caught in the grab are summarized in Table VI. The hauls



TEXT-FIG. 2.—Number of animals caught by the Priestman grab.

are arranged in order of depth, and one Lagoon haul (Sta. 137, 46 m.) is included to give an idea of the abundance of life in very shallow water. The total catch of animals at each depth has been divided by the number of hauls, thus giving an average of the numbers caught at each depth. Where a haul was unproductive of life, through the grab jamming or failing to close properly, the haul has been excluded from the averaging. In many cases the figures in the last two columns are only approximate, as the number of specimens obtained was not always recorded. Many records of grab hauls only mention " few ", " several " or " numerous " specimens of a species.

The figures in the column, " Average animals per haul ", represent the number of animals present on or in 0·5 sq. m. of the deposit, the area covered by the Priestman grab.

A sufficient number of results are available to make it possible to graph the relationship between the depth and the density of fauna. The average number of animals collected is plotted against 50 m. intervals of depth (Text-fig. 2).

Table VI.

Depth (m.)	Station.	Number of successful hauls.	Total animals.	Average animals per haul.	Average 50 m.
46	137	1	28	28	28
91	73, 90, 178, 189	3	26	9	9
101	103, 151	1	7	7	4
110	204	1	1	1	
113	112	1	?	?	
155	74	1	?	?	21
177	205, 164	1	2	2	
183	190	2	68	34	
193	89	1	12	12	
201	28, 75	2	53+ several	(30)	14
207, 209	104, 126	2	15+ several	(10)	
220	113	1	..	..	
238	149	1	4+ several	(6)	
256	206	1	18+ several	(22)	17
274, 275	88, 163, 191, 179b	4	72+ several	(20)	
280	105	1	..	..	
310	179a	1	..	..	0
353	114, 165	1	..	..	10
366	192	1	10	10	
375	207	1	16	16	
397	180	1	15	15	
411	77	1	..	..	0
423	150	1	..	..	
805	125	1	..	..	0

Owing to the grab being jammed by rocky material and to indefinite statements of the number of animals caught the graph is based on one result only over the depth range 100–150 m. Similar considerations apply to the range 300–350 m., where of three hauls

one was jammed and two empty of animals, though at one of the stations a haul with the Agassiz trawl brought up a rich fauna. Hence no value, however approximate, can be given for this range. The number of hauls is small. In most 50-m. ranges only two to three hauls were made, so that the above graph can only be taken as a rough approximation. The maximum number of results was six in the range 150–200 m.

A sharp falling off from the number of individuals present in the shallow water of the littoral zone is indicated in the first 100 m. There is a subsequent increase again, reaching a maximum in about 200 m. due to the replacement of the littoral by the Continental Shelf fauna, which reaches its greatest development in about this depth. Below 200 m. there is a steady falling off in the numbers caught at increasing depths. Below 397 m. no animals were caught in depths of 411, 423 and 805 m. in which the grab was used.

As already mentioned (p. 114), the same zonation has been recorded by Alcock (1890, p. 426) off the Ganjam coast. This author distinguishes three zones of life on this coast as follows :

1. 0–14 fms. (0–26 m.).

   Here life is abundant, and hauls may contain several species in large numbers. This zone corresponds to the 0–50 m. section of Text-fig. 2.

2. 20–40 fms. (37–74 m.).

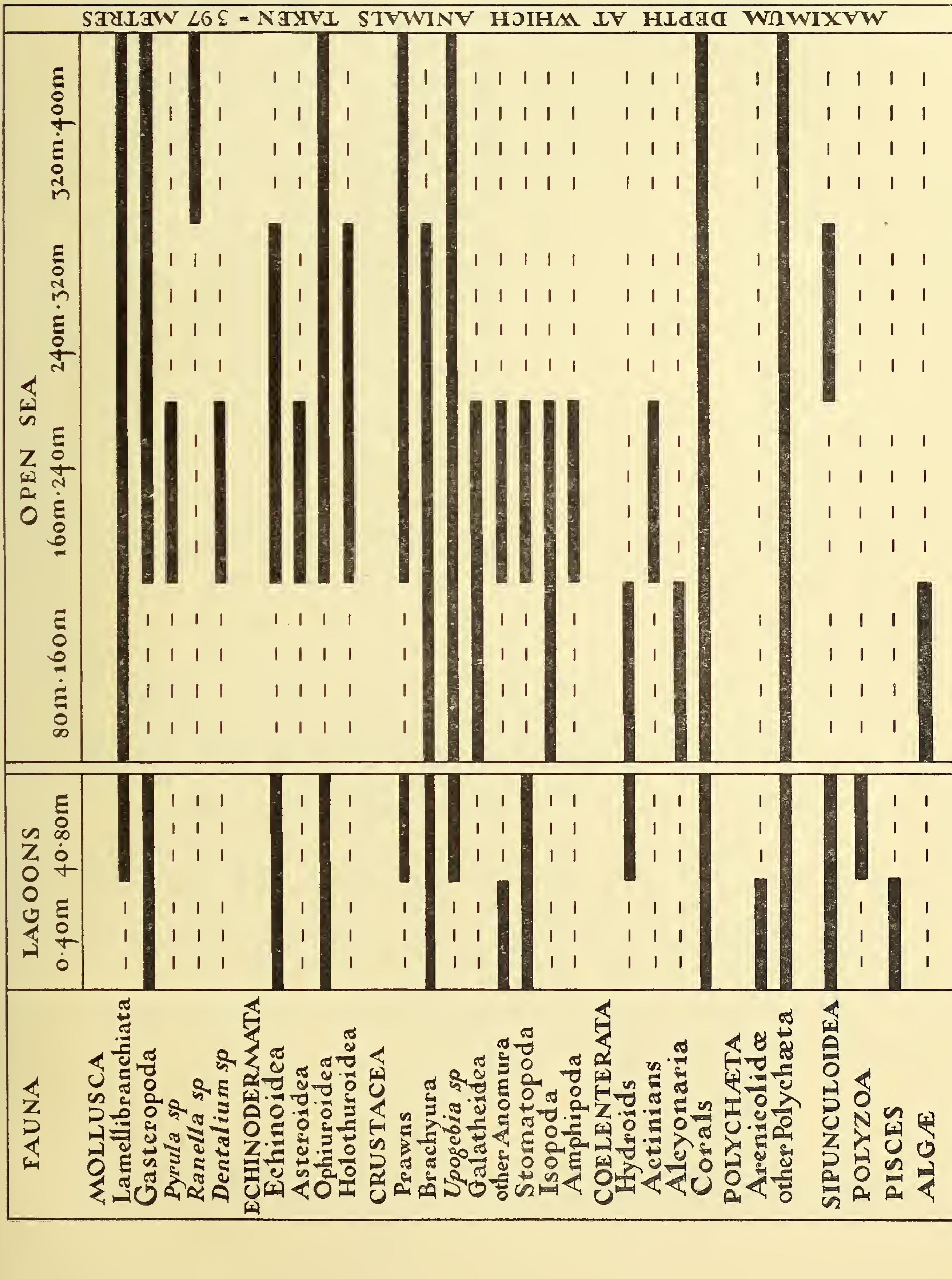
   In this zone the hauls are usually small and most of the species from the previous zone are absent. It corresponds approximately with the region from 100–150 m. on Text-fig. 2.

3. 70–100 fms. (130–185 m.).

   Large and varied hauls were taken in this zone and the forms have a distinct bathybial facies. This zone is the same as that represented on the graph by the peak in 150–200 m.

There is a striking similarity between the form of this graph (Text-fig. 2) of the living animals and Text-fig. 1, in which the percentage of animal remains was plotted against depth. In Text-fig. 1 the minimum percentage of fragments occurs in deeper water, between 500 and 600 m. as against 100–150 m. here. This may reasonably be considered as due to the transport of dead shells and other remains, by current movement, into deeper water. Such transport is probably ineffective below 500 m. The graph of the remains (Text-fig. 1) has a peak at about 1100–1200 m., due to the great deposition of tests of pelagic Foraminifera in these depths. It cannot be correlated with the maximum in 200 m. shown in Text-fig. 2. As already stated this is due to the full development of the Continental Shelf fauna here. It has already been shown (p. 113) that the zone of maximum sedimentation, the " mud-line ", occurs at about 500 m. Apparently the largest number of animals occurs in the upper part of the zone of heavy sedimentation and not where sedimentation is at a maximum.

(b. ii) *The depth range of animals from the green and brown muds taken by the Priestman grab.*—Thirty of the forty Priestman Grab hauls contained living animals. The most frequently occurring organisms were : Polychæta (24 times), Lamellibranchiata and Brachyura (10 times), Ophiuroidea and Porifera (8 times), Prawns and Stomatopoda (6 times). These and the other genera and groups of animals obtained are shown on Text-fig. 3. Those not mentioned above only occurred four times or less. Thus no less than 80% of the successful hauls yielded worms which were far more frequent than other groups ; the next in order of frequency, Lamellibranchiata and Brachyura, both occurred in only one-third of the successful hauls. This is a striking illustration of the widespread



Text-fig. 3.—Depth range of animals obtained in the Priestman grab.

distribution and abundance of the Polychæta, compared with other organisms, in the shallow waters of the Arabian Sea. Only the above-mentioned seven groups appear to be at all uniformly distributed, though others may be common locally.

The depth range of the animals collected is summarized in Text-fig. 3. It is evident from this figure that the lagoons support quite a varied fauna; sixteen of the twenty-seven groups or genera distinguished in the table were obtained there by the grab. Doubtless others occur, though not obtained by this means. The richest fauna on the Continental shelf is seen to occur about 160–240 m., nineteen groups being collected within this depth range as against eleven or less in the others. This has been seen already in Text-fig. 2 (p. 120) where the average number of animals per haul was plotted against the depth in 50-m. intervals and a maximum was found in 150–200 m. In shallower water (80–160 m.) fewer animals were obtained, whole groups such as Gasteropoda and Echinodermata being unrepresented in the hauls. Below the rich zone, also, the numbers obtained fell off considerably. In the next range, 240–320 m., only eleven groups occurred, and in the deepest of all, 320–400 m., the number was reduced to eight. It is worthy of note that seven of these, Lamellibranchiata, Gasteropoda, Ophiuroidea, Prawns, *Upogebia* sp., Corals and Polychæta, all have a very wide range. The first two and the last two of these were found from 80 m. downwards, and the other three in the next range from 160 m. downwards.

The distribution of the Sipunculoidea is curious: they were found several times in shallow lagoon waters and once in open water at a depth of 274 m., with no indication of their occurrence in shallow open water. It is quite probable that this is due solely to the small number of records (four only).

(c) *Coarser Deposits.*

The remaining terrigenous deposits consists of sands, calcareous conglomerates, and mud with a large amount of rock fragments or calcareous rubble, *i. e.* unidentifiable calcareous material of animal origin. The rock and rubble deposits will be considered separately from the sands. Apart from one sample containing rock fragments from 1415 m. (Sta. 42) and one of calcareous conglomerate from 1167 m. (Sta. 6) all these deposit samples are from comparatively shallow water. The deepest is from 366 m.

(c. i) *The conglomerates.*—Seven samples were obtained containing much coarse rubble and rock fragments. Of these, three (from Stas. 6, 45, and 72) consisted of a calcareous conglomerate formed of fragments of the shells of recent animals cemented together. One (Sta. 111) consisted almost entirely of loose calcareous rubble, and the remaining three (Stas. 42, 67, 209) of limestone fragments, rubble and green mud. Sta. 67 also yielded fragments of serpentinized enstatite peridotite.

The conglomerate contains the remains of a limited fauna. In the material from Sta. 6 the following species of Pteropoda were identified:

Limacina inflata	*Diacria quadridentata.*
Creseis acicula.	*Cavolinia longirostris.*
Cr. virgula.	*Atlanta* sp.
Hyalocylis striata.	

A few *Globigerina bulloides* and Gasteropod fragments were present. The rest of the conglomerate consisted of rather small shell fragments, occasional bottom Foraminifera

and Echinoid spines. Most of the remains are those of shallow-water attached animals and Foraminifera.

The green mud from Sta. 209 contains a considerable number of species of Pteropoda, in addition to broken shells of *Conus* and *Solarium* and the solitary corals *Flabellum*, *Rhizotrochus* and *Caryophyllia*. This deposit is near the area of Pteropod ooze at the south end of the Red Sea, which accounts for the presence of so many Pteropoda.

Table VII summarizes the nature of the deposit at these seven stations :

TABLE VII.

Station.	Depth (m.).	Deposit-type.	Chief animal remains.
6	1167	Calcareous conglomerate	Pteropoda.
42	1415	Limestone ; green mud	Very few Foraminifera *Rhizammina algæformis*; Poriferan spicules.
45	38	Calcareous conglomerate	*Lithothamnion*, Polyzoa, Polychæta, *Pavona*, etc.
67	274	Limestone ; serpentinized enstatite peridotite; green mud	Pelagic and benthic Foraminifera, Pteropoda; fragments of benthic organisms.
72	73	Shelly conglomerate	Shells, especially *Turritella* sp.
111	73–165	Calcareous rubble	Encrusting shallow-water organisms.
209	366	Limestone ; green mud	Pteropoda; few solitary corals ; *Rhabdammina* sp.

(c. ii) *Sands.*—Nine samples of sands were obtained from shallow water ranging from $13\frac{1}{2}$ m. down to 220 m. They all contain some siliceous material though the percentage varies considerably, as the following table (Table VIII) shows :

TABLE VIII.

Station.	Depth (m.)	% insoluble residue (mainly siliceous).
24	73–200	13·6
27	37	6·2
53	13·5	32·4
80	16–22	..
89	193	..
103	101	11·4
112	113	..
113	220	38·0
178	91	..
Average	110 m.	20·3%

The type of sandy deposit is influenced considerably by the relative amount of siliceous

material present. Three representative samples are shown on Pl. II, figs. 2–4. The first (fig. 2), from Sta. 178, contains practically no siliceous material, and is a typical calcareous sand composed largely of rounded Molluscan shell fragments together with lesser amounts of other organisms, of which an Echinoid spine, *Balanus* scutum and fragments of Polychæt tubes, are identifiable in the figure.

Fig. 3 shows another terrigenous sand with a considerable amount of quartz grains, from Sta. 163 off Zanzibar. The darker particles in the figure are the quartz grains, many of which are coloured brown ; calcareous remains appear white or pale grey. The shell content of this sand is low and the chief sources of calcium carbonate are fragments of solitary corals, Polyzoa and occasional Foraminifera. This deposit is intermediate between the calcareous sand of fig. 2, and the very siliceous sand from Sta. 113, off Zanzibar, shown in fig 4. At this latter station calcareous remains are varied but none are very abundant. Pteropod shells are an interesting source of calcareous material in this deposit, which contains 38·0% of siliceous material, chiefly quartz grains.

As is to be expected, the animal remains present are mainly those of shallow-water organisms, especially of attached forms, that require a hard bottom. A few remains of animals from muddy sand, *e. g. Uvigerina pygmæa*, occur, and also some remains of pelagic organisms, though these are rare. The following composite list illustrates the kinds of animals met with in these shallow-water deposits :

Pelagic :—

Foraminifera.

Globigerina bulloides.	*Orbulina universa.*
Globigerinoides rubra.	*Globorotalia menardii.*

Pteropoda.

Limacina inflata.	*Diacria trispinosa.*
Creseis acicula.	*Cavolinia globulosa.*
Cr. virgula.	*C. longirostris.*
Hyalocylis striata.	*C. uncinata.*
Clio pyramidata.	*Atlanta* sp.
Diacria quadridentata.	
	Fish otoliths.

Benthic :—

Foraminifera.

Rhabdammina abyssorum.	*Gaudryina rugulosa.*
Rhizammina algæformis.	**Quinqueloculina agglutinans.*
**Reophax* sp.	**Q. intricata.*
**Haplophragmoides canariense.*	**Q. rupertiana.*
**H. grandiformis.*	*Spiroloculina depressa.*
Textularia agglutinans.	*Sp. grateloupi.*
**T. carinata.*	*Sp. grateloupi* var. *acescata.*
**T. corrugata.*	*Sigmoilina schlumbergeri.*
T. gramen.	*Triloculina tricarinata.*
**T. porrecta.*	*Tr. trigonula.*
T. sagittula var. *atrata.*	*Pyrgo anomala.*
**T. tuberosa.*	*P. murrhina.*
**T. trochus.*	*P. sarsi.*

P. vespertilio.
**Spirophthalmidium acutimargo.*
**Nubecularia tuberosa.*
**Carterina spiculotesta.*
Placopsilina cenomana.
Robulus convergens.
R. costatus var. *multicostatus.*
R. orbicularis.
Lenticulina rotulata.
Nodosaria flinti.
N. scalaris.
N. subscalaris.
Vaginulina legumen.
V. linearis.
**V. tricarinella.*
**Guttulina yabei.*
Sigmoidella elegantissima.
**Polymorphina ovata.*
**Nonion asterizans.*
**N. grateloupi.*
N. scaphum.
N. umbilicatulum.
**Nonionella ? auris.*
**Elphidium articulatum.*
El. craticulatum.
El. crispum.
**El. macellum.*
**Ozawaia tongaensis.*
Operculina gaimardi.
O. granulosa.
Heterostegina depressa.
Heterostegina operculinoides.
Sorites marginalis.
Marginopora vertebralis.
Alveolinella boscii.
Bolivina simpsoni.
**Chrysalidinella dimorpha.*
Uvigerina aculeata.
U. pygmæa.
U. tenuistriata.
**Discorbis globularis* var. *bradyi*
Gyroidina soldani.
Eponides præcinctus.
**Planopulvinulina dispansa.*
Rotalia calcar.
R. margaritifera.
R. papillosa.
Epistomina elegans.
**Sphæridia papillata.*
Amphistegina radiata.
**Planulina* sp.
Cibicides lobatulus.
C. refulgens.
Planorbulinella larvata.
Gyspina globulus.
G. vesicularis.
Carpenteria monticularis.
C. proteiformis.
C. utricularis.
Sporadotrema cylindricum.
Sp. mesentericum.
Miniacina miniacea.

Mollusca.
Conus sp.
Terebra sp.
Cadulus sp.
Dentalium sp.

Polyzoa.
Cellaria sp.
Haswellia sp.

Cirripedia.
Balanus sp.
Lepas sp.
Verruca sp.

* These species were found in the sands only.

Lithothamnioneæ, Hydrocorallinæ and *Hyalonema* spicules also occur in small quantities.

(d) *Globigerina Ooze.*

Globigerina ooze was obtained at sixteen stations ranging in depth from 353 to 3676 m.,

with one exceptionally deep sample from 4499 m. The average depth of the deposit below sea-level, computed from the station depths, is 2481 m. This depth compares favourably with the average depth of the " Valdivia " samples (Murray and Philippi, 1908, p. 140), some of which were obtained in the Indian Ocean, namely 2890 m. It is very near the average for the samples obtained by the same expedition in the north-west region of the Indian Ocean only, namely 2330 m. Taking these records into account an average depth for Globigerina ooze in the Arabian Sea of 2405 m. is obtained. This depth is slightly less than two-thirds the average depth for the deposit from the seas of the world given by Murray and Renard (1891, p. 214), namely 2002 fathoms (3696 m.). This average includes those deposits that could be called transitional ooze. If these were omitted, Murray's average depth for Globigerina ooze would be considerably lowered. The samples from below 4000 m. are mainly brown transitional oozes, but that from Sta. 173 at 4499 m. (the deepest at which Globigerina ooze was obtained) is exceptional in being a finely divided white Globigerina ooze with no appreciable amount of red clay.

The percentage of calcium carbonate has not been determined, but estimations were made of the weight of the recognizable Foraminiferal fragments, and these ranged from 9·7% to 48·9%; the average amount was 26·2%. The very high percentage of Foraminifera (48·9%) at Sta. 127 (at 4091 m.) is remarkable in that it is double that found at stations in similar depths. At this depth one would have expected the amount of calcium carbonate, and therefore of Foraminiferal tests, to have fallen off.

(e) *Transitional Ooze.*

Ooze transitional from Globigerina ooze to red clay was obtained at six stations ranging in depth from 3722 m. to 4234 m. The average depth of the samples obtained was 4038 m. These deposits all leave a considerable insoluble residue resembling red clay.

The biological composition of this deposit is very similar to that of pure Globigerina ooze. The main differences are that transitional ooze usually contains fewer Foramiferal tests and other calcareous remains, and that rather fewer benthic species of Foraminifera are present.

The biological composition of the two deposits is discussed below.

Biological Composition of Globigerina Ooze and Transitional Ooze.

The composition of these deposits from the biological standpoint is limited to a comparatively small number of pelagic forms but includes many benthic species. Only sixteen of the twenty-five truly pelagic species of Foraminifera listed by Cushman (1933, p. 44) were obtained in these oozes. The following is a list of all the species identified :

Pelagic :—

Globigerina bulloides.
Gl. dubia.
Gl. inflata.
Globigerinoides conglobata.
Gl. rubra.
Gl. sacculifera.
Globigerinella æquilateralis.
Gl. digitata.
Orbulina universa.
Pulleniatina obliquiloculata.
Sphæroidinella dehiscens.
Globorotalia canariensis.
Gl. crassa.
Gl. menardii.
Gl. truncatulinoides.
Gl. tumida.

Pteropoda.

Limacina inflata.
Creseis sp.
Cuvierina columnella.
Cavolinia sp.
Diacria quadridentata.
Atlanta sp.

Benthic :—

Foraminifera.

Rhabdammina abyssorum.
Rh. abyssorum var. *radiata.*
Rh. discreta.
Rh. linearis.
**Marsipella elongata.*
**Psammosphœra fusca.*
Saccammina sphœrica.
**Tholosina bulla.*
**Hyperammina friabilis.*
**Dendrophrya ramosa.*
**Reophax nodulosus.*
**Ammodiscus incertus.*
**Ammodiscoides turbinatus.*
**Ammolagena clavata.*
**Cyclammina compressa.*
Spiroplectammina milletti.
**Textularia flinti.*
T. gramen.
T. sagittula.
Verneulina propinqua.
Gaudryina baccata.
Clavulina communis.
**Spiroloculina ? tenuis.*
Sigmoilina schlumbergeri.
**Triloculina* sp.
Pyrgo anomala.
P. denticulata.
P. depressa.
P. lucernula.
P. murrhina.
P. serrata.
Cornuspira carinata.
Planispirina sphœra.
Robulus convergens.
**R. subaculeatus.*
**Lenticulina subalata.*
Marginulina glabra.
Dentalina filiformis.
**Nodosaria hirsuta.*
**N. pauperata.*
Vaginulina legumen.
**Lagena distoma.*
Nonion umbilicatulum.
**Bolivinita quadrilatera.*
Bulimina aculeata.
B. ovata.
B. pyrula.
Virgulina subsquamosa.
Bolivina dilatata.
Uvigerina aculeata.
U. tenuistriata.
Siphogenerina striata var. *curta.*
**Rotalia broekhiana.*
Epistomina elegans.
Cancris auriculus.
Cymbaloporetta squamosa.
Ehrenbergina pacifica.
Chilostomella ovoidea.
Planulina ariminensis.
Pl. wuellerstorfi.
Cibicides lobatulus.

* These species occurred only in Globigerina ooze.

Lamellibranchiata, larval Gasteropoda, Echinoderm fragments, Ostracod valves and a few Coccoliths complete the list of calcareous remains present.

Siliceous remains include a few Diatoms, Radiolaria and Poriferan spicule-fragments.

As is to be expected, Foraminifera form the bulk of the animal remains. The pelagic forms, though smaller in the number of species, are by far the commonest. Except in occasional samples the bottom-living forms are scarce, and occur for the most part in those

samples of Globigerina ooze bordering on terrigenous muds. The above list of Foraminifera is in fair agreement with that given by Murray and Renard (1891, p. 214) for Globigerina ooze, and also with that of Hanzawa (1928, p. 68) for material from the south-west part of the North Pacific. The latter author, however, lists many more bottom-living species, the majority of which were very rare. Other organisms are usually conspicuous by their absence and again tend to occur more frequently in the deposits from lesser depths. Coccoliths are exceedingly rare, and were identified in a few samples only after a careful search of the finest material. Evidently they are not typical of the Arabian Sea, though, according to Murray and Renard (1891, p. 258), they are said to " play a most important part in all deep-sea deposits, with the exception of those laid down in polar and sub-polar regions".

As the above list shows, few siliceous remains occur. Radiolarian skeletons and Poriferan spicules could probably be demonstrated in most, if not all, of the samples of Globigerina ooze by dissolving out the calcium carbonate from a sufficient quantity; but such remains are exceedingly rare, and of no importance as ooze-forming organisms in this type of deposit. Diatom remains are even less common and are usually fragmentary.

Typical samples of the deposit are shown on Pl. II, figs. 5, 6. That shown on fig. 6, from Sta. 167, is of interest because of the great abundance of fragments of *Globorotalia menardii*, which is by far the commonest species in the deposit at this station.

(f) *Pteropod Ooze.*

Under the category of Pteropod ooze I have included all deposits in which the Pteropod and Heteropod shells total more than 5·0% by weight of the deposit. These deposits are all from the borders of the terrigenous mud areas, and might equally well be classed with these deposits except for the numerous remains of Pteropoda. Eight such deposits were found along the African coast, in the Gulf of Aden, at the southern end of the Red Sea, and in the Gulf of Oman, containing from 5·1% to 14·2% of Pteropod shells, with an average of 8·9% (average of six samples). A further ten samples, in which the shells amounted to less than 5·0% (averaging 1·6%) have been classed with the green, brown or grey muds, to which they more properly belong.

The depth of this deposit below the surface averages 255 m., with extremes of 155 m. and 411 m. This is far less than the average obtained by the " Valdivia " of 788 m. for twelve samples, and for those samples from the north-west area of the Indian Ocean alone the average obtained was 830 m. An average depth of 543 m. for the deposit in the North-west Indian Ocean is thus obtained. Both the present records and those of the " Valdivia " are from much shallower water than those obtained by the "Challenger". Murray and Renard give an average depth of 1044 fms. (1927 m.) for Pteropod ooze.

Pteropod ooze may exhibit marked differences in appearance in different areas. Thus the deposit from Zanzibar and that from the Gulf of Oman are formed of the elongated conical shells of *Creseis acicula* and *C. virgula* with some of the striated *Hyalocylis striata* (see Pl. III, fig. 2); other species of Pteropoda are rare or absent. Other deposits, as for instance those from the south end of the Red Sea, are composed largely of the shells of *Cavolinia* spp., all nine species of which are frequently present, as well as species of *Clio* and *Creseis* (see Pl. III, fig. 1).

The biological composition of a Pteropod ooze is shown by the following lists of species:

Pelagic :—

Pteropoda.

Peraclis reticulata.	*Styliola subula.*
Limacina inflata.	*Clio pyramidata.*
L. bulimoides.	*Cuvierina columnella.*
L. helicina.	*Diacria quadridentata.*
L. trochiformis.	*Cavolinia globulosa.*
Creseis acicula.	*C. longirostris.*
Cr. virgula.	*C. uncinata.*
Hyalocylis striata.	*Atlanta* sp.

Foraminifera.

Globigerina bulloides.	*Globigerinella digitata.*
Gl. dubia.	*Orbulina universa.*
Globigerinoides conglobata.	*Pulleniatina obliquiloculata.*
Gl. rubra.	*Candeina nitida.*
Gl. sacculifera.	*Globorotalia canariensis.*
Globigerinella æquilateralis.	*Gl. menardii.*

Benthic :—

Foraminifera.

Rhizammina algæformis.	*Nodosaria scalaris.*
Reophax sp.	*N. vertebralis.*
Trochamminoides proteus.	*Saracenaria italica.*
Cribrostomoides bradyi.	*Nonion boueanum.*
Textularia agglutinans.	*Operculina granulosa.*
T. conica.	*Sorites marginalis.*
T. pseudocarinata.	*Bulimina ovata.*
T. rhomboidalis.	*B. pagoda.*
T. sagittula var. *fistulosa.*	*B. pyrula.*
Clavulina angularis.	**Virgulina* sp.
Cl. communis.	*Bolivina amygdalæformis.*
Cl. pacifica.	*B. beyrichi.*
Cl. tricarinata.	*B. beyrichi* var. *alata.*
**Quinqueloculina* sp.	**B. compacta.*
Spiroloculina depressa.	*B. robusta.*
Sp. grateloupi.	*Uvigerina brunnensis.*
Sigmoilina schlumbergeri.	*U. pygmæa.*
Triloculina tricarinata.	**Discorbis vilardeboana.*
Pyrgo depressa.	**Eponides haidingeri.*
P. sarsi.	*Ep. præcinctus.*
P. vespertilio.	*Rotalia margaritifera.*
Robulus acutauricularis.	*R. papillosa.*
R. calcar.	*Ehrenbergina pacifica.*
R. denticuliferus.	*Chilostomella ovoidea.*
R. gibbus.	*Cibicides lobatulus.*
**R. papillosus.*	*C. refulgens.*
Nodosaria pauciloculata.	*Miniacina miniacea.*
**N. raphanus.*	

* These species were found in Pteropod ooze only.

Pteropod ooze is thus characterized by the large number of shells, and shell-fragments, of Pteropoda, the small number of *Globigerinæ*, though all the species found in Globigerina ooze may be present, and the large number of benthic Foraminifera, the number of species of these last (60) being practically the same as that found in Globigerina ooze (61). The species, however, are mainly those found in green mud. Forty-one species are common to the green mud and Pteropod ooze and only eight to Pteropod ooze and Globigerina ooze. This is, of course, to be expected, as the Pteropod oozes occur on the edge of the green muds, whereas Globigerina ooze extends into much deeper water. Most of the species occur in small numbers only.

Other remains of organisms, such as shell and Echinoderm fragments, are present, as in green mud. The average composition of four Pteropod oozes is given in Table IX, but owing to the extreme variability in the percentages the average values have little significance.

Table IX.

Group.	Average % deposit.	Variation.
All remains . . .	58·0 .	74·7–39·0
Echinodermata . . .	5·7 .	16·9–0·9
Lamellibranchiata . .	10·5 .	22·9–0·4
Gasteropoda . . .	9·3 .	17·5–0·9
Pteropoda	9·7 .	14·2–5·1
Pisces	0·8 .	1·7–0
Other remains . . .	22·0 .	..
Total . . .	58·0	

The 22% "Other remains" is composed of various other macrofauna and Foraminifera.

The number of species of Pteropoda actually found in the deposits is low. The species of *Cavolinia* especially are often lacking, though all the known species occur in the plankton of the north-west region of the Indian Ocean. Murray and Renard (1891, p. 224) list thirty-five species of Pteropoda and thirty-two of Heteropoda that may occur in Pteropod ooze. Only fifteen species were actually present in the samples examined, though six more were found in other types of deposit. Hanzawa (1928, p. 73) only found nine species of Pteropoda in oozes from the north Pacific. The Heteropoda have not been identified, but *Atlanta* spp. were of frequent occurrence both in Pteropod ooze and in other deposits. The distribution of Pteropod shells in the deposits is discussed elsewhere (p. 145).

The following six species of Pteropoda were found occasionally in various deposits though not in Pteropod ooze :

Peraclis bispinosa.	*Cavolinia gibbosa.*
Clio cuspidata.	*C. inflexa.*
Diacria trispinosa.	*C. tridentata.*

A comparison of the species identified from the plankton and the deposits shows the following differences :

Species apparently present only in—

Plankton.	Deposits.
Clio chaptali.	*Peraclis bispinosa.*
	P. reticulata.
	Limacina bulimoides.
	L. helicina.
	Cuvierina columnella.
	Cavolinia gibbosa.

Clio chaptali would appear to be a rare Arabian Sea species. It occurred only twice in the plankton hauls made by the expedition, each time a single specimen being obtained. The species found in the deposits only were likewise infrequent except for *Cuvierina columnella* and *Cavolinia gibbosa*. This is probably due to the small size and delicate nature of the shells of *Peraclis* and *Limacina*, which tend to break up readily. The same reason probably accounts for their absence from the plankton hauls. It is highly probable that the shells were damaged by shaking or by the preservative and so were lost or rendered unrecognizable. *Cuvierina columnella* and *Cavolinia gibbosa* have a much more resistant shell, and would be expected to withstand contact with the particles of the deposit. These two species, however, were obtained only in the Zanzibar area, where they were quite frequent. It is remarkable that they did not occur in the plankton. At present these species have not been found alive, or as deposit-shells north of the equator in the Arabian Sea, though there are several records of both species from south of the line.

(g) *Red Clay.*

Only three samples of a deposit were obtained that could be assigned to this formation. They ranged in depth from 4285 m. to 5082 m., averaging 4720 m. This depth is 500 m. less than the average obtained by the " Valdivia " for red clay, 5288 m., and 300 m. less than the average given by Murray and Renard (1891, p. 190), 2730 fms. (5040 m.), for red clay in general.

The three samples of red clay are very pure. Calcareous remains were found in one sample only (Sta. 100), in very small quantities. Siliceous remains occurred in the samples from Stas. 100 and 101, a few sponge spicules and *Coscinodiscus* sp. being present but no Radiolaria. The third sample from Sta. 166 contained no calcareous or siliceous remains.

Two other samples from Stas. 134 and 167 contained a large amount of red clay but, as they also contained large numbers of the species typical of Globigerina ooze, they have been included under the heading of " Transitional Ooze ".

The deposit from Sta. 166 was associated with large numbers of manganese nodules, about 125 kg. of which were obtained in one haul of the trawl.

The red clay, like the grey clay already described, supports a very poor fauna and contains very few remains of pelagic organisms. This absence of remains in red clay has always been ascribed, among other factors, to the immense pressure in the depths raising the solubility of calcium carbonate and silica so that all the *Globigerinæ* and other remains are dissolved, with the exception of some of the siliceous structures. In grey clay there is a very poor fauna, but owing to the lesser depth this cannot be ascribed to the high pressure. It is thus probable that the cause of the paucity of the fauna is different in the two instances. In the grey clay area of the northern Arabian Sea the bottom-water is poor in oxygen, and in parts the deposit, and perhaps also the overlying water, is charged with

hydrogen sulphide. Conditions are thus unfavourable for animal life. Farther south, in the red clay area, the oxygen content of the water is slightly higher. The amount of organic matter is about the same as in the grey clay. These then cannot be the factors limiting life. It is possible that the depth is the limiting factor here, very few animals having become adapted to life in the greatest depths.

The increased oxygen-content of the water appears to have a considerable effect on the deposit. At the northern end of the Arabian Sea, where the oxygen deficiency is greatest, grey clays are deposited. Further south, under conditions of better oxygenation, red clays are laid down.

(h) *Deposits from the Maldive Archipelago.*

These deposits consist of sands and muds from the lagoons and the outer slopes of the atolls. Nine samples were obtained from the lagoons and eleven from the outer slopes of the atolls.

(h. i) *The Lagoon muds.*—Five samples of mud and four of sand were obtained in the lagoons. The composition of the two deposits is very different and there appears to be little overlap of the two deposits. The depth and percentage of large material of animal origin in the muds is given below :

Station.	Depth (m.).	% large animal remains.
137	46	8·5
142a	31	(24·9)
142b	37	6·4
147	27	6·7
160	37	5·4
Average	36 metres	6·75% (of 4 only)

The percentage of larger animal fragments is thus fairly constant about 7·0%, except for Sta. 142a from Fadiffolu Atoll. These deposits contain remains of most shallow-water bottom-living organisms, but never in any quantity. Pelagic animals are represented by :

Foraminifera.

Globigerina bulloides.
Gl. dubia.
Globigerinoides conglobata
Gl. rubra.
Gl. sacculifera.
Globigerinella æquilateralis.
Globigerinella digitata.
Orbulina universa.
Globorotalia canariensis.
Gl. crassa.
Gl. menardii.

Pteropoda.

Creseis acicula.
Cr. virgula.
Diacria quadridentata.
Cavolinia longirostris.

Bottom-living Foraminifera are few in species and rare in comparison with other deposits. The following species occur :

**Bathysiphon filiformis.*
Aschemonella ramuliformis.
Trochamminoides proteus.
Textularia conica.
T. foliacea.
**T. haueri.*
Clavulina communis.
**Quinqueloculina ferussacii.*
**Q. reticulata.*
**Massilina inæqualis.*
Spiroloculina canaliculata.
Sp. grateloupi.
Pyrgo vespertilio.
Laticarinina pauperata.
Dentalina consobrina var. *emaciata.*
Nodosaria pyrula.
Nodosaria sp.
Nonion boueanum.
Elphidium craticulatum.
Operculina gaimardi.
O. granulosa.
Heterostegina depressa.
H. suborbicularis.
Amphisorus hemprichi.
Borelis melo.
Alveolinella boscii.
Epistomina elegans.
Amphistegina radiata.
Gypsina globulus.

* These five species were found in the Lagoon muds only.

Crustacean material is quite common in most of these muds. Segments of the limb skeleton and large fragments of the carapace are of frequent occurrence. Other remains are very variable. Gasteropoda were abundant at Sta. 137, but were rare at Sta. 160, where small Lamellibranch valves were very common. *Creseis* spp. were present in four of these muds and were abundant at Sta. 160, but were absent from Sta. 142a. The type of material left on sieving coral mud is shown on Pl. III, fig. 6, which is from material obtained at Sta. 142b.

(h. ii) *The Lagoon sands.*—In the lagoon sands fragments of animal origin are very plentiful. Few pelagic organisms, but many bottom-living forms, are present among the remains. These sands and gravels are almost entirely of calcareous origin, and consist mainly of the remains of bottom-living species, especially corals and shells and sometimes also Foraminifera, as at Sta. 139, where they form over 50% by weight of the deposit (see Pl. III, fig. 3). Coralline algæ frequently form a large part of the deposit, as at Sta. 144, where fragments of *Halimeda* sp. are common (see Pl. III, fig. 4). Table X below gives the amount of animal fragments in these sands :

TABLE X.

Station.	Depth (m.).	% large animal remains in deposit.
139	57	87·2
141	44	50·6
144	31	42·7
161	46	31·5
Average	45 metres	53·0%

The percentage of larger animal material thus varies very considerably in the sands, but is always of a high order. The actual percentage probably depends upon the amount of tidal scour to which the deposit is exposed.

The lagoon sands are characterized by the absence of pelagic organisms. The only true pelagic organism found was a shell of *Atlanta* sp. *Tretomphalus bulloides* occurred in small numbers, but this species is not a true pelagic Foraminiferan, as it is attached in the young stages and only becomes pelagic as a fully grown organism. It is a shallow-water species. The following is a list of the Foraminifera present:

Textularia agglutinans.	*Operculina gaimardi.*
**T. candeina.*	*O. granulosa.*
T. conica.	*Heterostegina depressa.*
T. foliacea.	*H. suborbicularis.*
T. gramen.	*Marginopora vertebralis.*
**T. pseudotrochus.*	*Borelis melo.*
Quinqueloculina kerimbatica.	*Alveolinella boscii.*
**Q. parkeri.*	*Amphistegina radiata.*
**Massilina australis.*	*Calcarina defranci.*
Spiroloculina grateloupi.	*Cymbaloporetta bradyi.*
**Sp. tenuissima.*	*C. squamosa.*
**Schlumbergerina alveoliniformis.*	**Acervulina inhærens.*
Triloculina oblonga.	*Gypsina vesicularis.*
Tr. tricarinata.	*Carpenteria proteiformis.*
Placopsilina cenomana.	*C. utricularis.*
**Robulus* sp.	*Homotrema rubrum.*
Elphidium craticulatum.	*Sporadotrema cylindricum.*
El. crispum.	*Miniacina miniacea.*
Operculinella cumingi.	

* These species were identified from lagoon sands only.

In addition to the above, remains of Alcyonaria, Polychæta, Lamellibranchiata, Gasteropoda, Scaphopoda and Echinodermata occur.

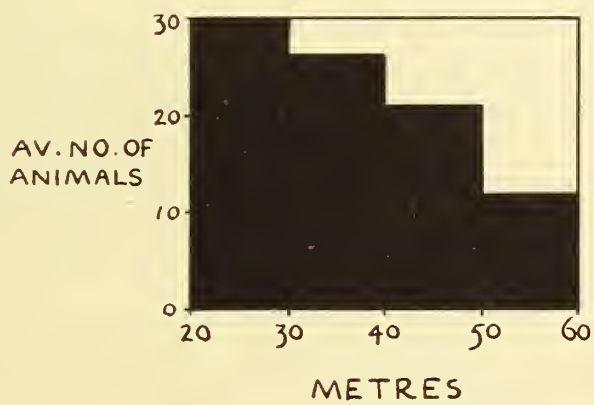
The muds and sands of the lagoons thus differ considerably *inter se* in their contained organic materials. The muds tend to contain a representative selection of pelagic species which are almost entirely absent from the sands. The sands, on the other hand, are composed of remains of benthic organisms, especially Foraminifera, which may be present in considerable numbers. The bottom-living Foraminifera in the two deposits belong mainly to different species. Twenty-eight species were identified from the muds and thirty-six from the sands, but only ten species are common to both deposits. Most of these latter are common, widely-distributed forms, such as *Alveolinella boscii* and *Amphistegina radiata*, that occur over a wide depth range, and in deposits varying from coarse littoral sands and gravels to fine muds from several hundred metres' depth.

It follows, then, that the lagoon bottom must present two very different types of habitat. There is the fine calcareous mud or ooze, apparently accumulating in calm water and in some cases containing sulphuretted hydrogen. Alternatively there are hard sandy or even gravel bottoms, exposed to current action, which keeps the mud from accumulating, and which are suitable for an entirely different set of animals.

The numbers of living animals obtained in hauls with the Priestman grab are shown in Table XI.

TABLE XI.

Depth (m.).	Station.	Number of successful hauls.	Animals. Total.	Animals. Average haul.	Animals. Average 10 m. interval.	Remarks.
27	147	1	30	..	30	..
31	142a	1	0	22	26	H_2S
	144		22			..
37	142b	2	15	29		H_2S
	160		42			H_2S
44	141	1	31	..	21	..
46	137	2	27	17		H_2S
	161		6			..
57	139	1	12	..	12	..



TEXT-FIG. 4.—Number of animals caught by grab in the lagoons of the Maldives.

At Sta. 142a no animals were caught and H_2S was present in the mud. This station was therefore neglected in obtaining the average number of animals per haul, as elsewhere the presence of this gas did not exclude the fauna. The gas was present at Stas. 137, 142b and 160, but animals were caught at all of these.

The above figures are reproduced in Text-fig 4. They indicate that there is a high population in the lagoons in about 20–30 m., which falls off steadily as the depth increases. There are no records from below 57 m., but as this is near the maximum depth for most lagoons we may expect the deeper waters to support about this number of animals per 0·5 sq. m.

There was no H_2S at Sta. 161 to account for the very low figure of only six animals in the haul from 46 m., and Sta. 137 at the same depth gave the second best haul in the lagoons, 27 animals being caught, despite the presence of hydrogen sulphide in a concentration estimated at 4·9 mgrm. per litre of water aspirated off the mud.

(h. iii) *Deposits from the Outer Reef-slopes.*—Eleven samples were collected from the outer slopes of the reefs in depths from 101 to 1280 metres. The majority are clean or muddy sands, with varying amounts of animal remains as Table XII indicates.

Table XII.

Station.	Depth (m.).	% animal remains.
143	797	78·0
145	494	48·3
149	238	..
151	101	..
152	878	65·6
157	229	..
158	914	..
159	1280	(5·5)
163	274	35·9
164	183	30·5
165	366	86·3
Average	523 metres	57·4% (of 6 only).

The percentage of animal remains in these deposits is again high—higher even than in the shallower lagoon sands. The deposit is, however, of a finer nature, as much of this percentage is made up of the tests and fragments of *Globigerinæ* and other pelagic organisms. Apparently much of the finest material is removed from this region by current action so that a fine sand is deposited instead of a mud, as in parts of the lagoons. The removal of fine mud only seems to occur down to about 1000 metres, as below this (*e. g.* at Sta. 159) mud is found with only a low percentage of animal fragments, and which approaches a Globigerina ooze in its composition. Coral muds thus appear to grade into Globigerina ooze at about 1000 metres. A sample of the animal remains occurring in these "slope" deposits, from Sta. 163, is shown on Pl. III, fig. 5.

The Foraminifera represent a very mixed fauna, as the deposit has characteristics of several of the more distinct deposit-types. Thus in shallow-water samples species from the sands and muds of the lagoons occur. In deeper water the deposit occupies the place of the terrigenous muds on the Continental slope, and many of the species occurring in the green and brown muds occur here also. Throughout its range the deposit contains considerable numbers of pelagic species, especially in the lower depths, where it grades into Globigerina ooze. Some of the bottom-living species of the Globigerina ooze are also present. Finally there are a number of Pteropoda present, as the deposit occupies the depths in which Pteropod ooze might be expected to occur. In this the deposit again parallels the green muds on the edge of the Globigerina ooze, which contain many Pteropoda and sometimes pass into Pteropod ooze.

The following is a list of the Foraminifera and Pteropoda found in this deposit:

Foraminifera.

Globigerina bulloides.
Gl. dubia.
Globigerinoides conglobata.
Gl. rubra.
Gl. sacculifera.
Globigerinella æquilateralis.
Gl. digitata.
Orbulina universa.
Pulleniatina obliquiloculata.
Sphæroidinella dehiscens.
Globorotalia canariensis.
Gl. crassa.
Gl. menardii.
Gl. truncatulinoides.
Gl. tumida.

Reophax scorpiurus.
Haplostiche dubia.
Aschemonella ramuliformis.
Haplophragmoides scitulum.
Ammobaculites calcareum.
Spiroplectammina milletti.
Textularia agglutinans.
T. conica.
T. foliacea.
T. gramen.
T. sagittula.
Verneulina bradyi.
V. triquetra.
Gaudryina baccata.
G. rugulosa.
Clavulina communis.
Cl. parisiensis.
Quinqueloculina kerimbatica.
Spiroloculina depressa.
Sp. grateloupi var. *acescata.*
Sigmoilina schlumbergeri.
Triloculina oblonga.
Tr. tricarinata.
Pyrgo anomala.
P. denticulata.
P. milletti.
P. murrhina.
P. vespertilio.
Biloculinella globula.
Cornuspira involvens.
Robulus lucidus.
R. orbicularis.
Lenticulina d'orbignyi.
L. rotulata.
Dentalina elegans.
Nodosaria subscalaris var. *paucicostata.*
Saracenaria italica.
Lingulina grandis.
Polymorphina lanceolata.
Elphidium craticulatum.
El. crispum.
Operculinella cumingi.
Operculina gaimardi.
O. granulosa.
Heterostegina depressa.
H. operculinoides.
H. suborbicularis.
Sorites marginalis.
Amphisorus hemprichi.
Marginopora vertebralis.
Borelis melo.
Alveolinella boscii.
Bulimina aculeata.
B. elongata.
B. ovata.
Uvigerina pygmæa.
U. schwageri.
Siphogenerina columellaris.
S. raphanus.
Angulogerina carinata.
Gyroidina soldani.
Rotalia calcar.
Epistomina elegans.
Cancris auriculus.
Amphistegina radiata.
Calcarina defranci.
Cymbaloporetta bradyi.
C. squamosa.
Cymbaloporella tabellæformis.
Chilostomella ovoidea.
Planulina wuellerstorfi.
Laticarinina pauperata.
Cibicides lobatulus.
Planorbulinella larvata.
Gypsina globulus.
Carpenteria monticularis.
C. proteiformis.
C. utricularis.
Homotrema rubrum.
Sporadotrema cylindricum.
Sp. mesentericum.
Miniacina miniacea.

Pteropoda.

Limacina bulinoides.
L. inflata.
L. trochiformis.
Creseis acicula.

* These species were found only in the deposits from the outer slopes of the Atolls.

Table XIII.

Deposit.	Depth range (m.).	Average % animal remains.	Foraminifera. Pelagic.	Foraminifera. Benthic.	Pteropoda.	Diatoms.	Radiolaria.	Mollusca. L.=Lamell. G.=Gasterop.	Echinodermata.	Polychæta.	Pisces.
Grey clay . .	274–1703 (av. 867)	7·7%	6 spp.	8 spp.	7 spp.	..	..	L.+ G.+	..	..	+
Grey mud . .	1687–3556 (av. 3135)	4·8%	9 spp.	28 spp.	7 spp.	+	+	L.+ G.+	+	+	+
Terrigenous muds (gn. and br.)	91–2072 (av. 793)	9·3%	15 spp.	192 spp. Usually rare; some species locally abundant, e.g. Stas. 105, 185	17 spp.	*Coscinodiscus* locally abundant, e.g. Stas. 55, 56	..	Common, locally abundant	Usually present, often abundant	Common	Frequent
Terrigenous sand.	13·5–220	..	4 spp.	86 spp.	11 spp.	..	..	Very variable			Few otoliths
Conglomerate .	38–1415	..	Few	Very few	7 spp.	..	..	Few	Few	Few attached tubes	..
Globigerina ooze .	353–4499 (av. 2779)	27·3%	Av. 26·2%		7 spp.	+	+	Very few			Frequent
			16 spp.	61 spp. 44 as in gn.m.							
Pteropod ooze .	155–411 (av. 255)	58·0%	12 spp.	60 spp., 8 as in gl. oz., 41 as in gn.m.	14·2–5·1%; 16 spp.	..	..	L. av. 10·5% G. av. 9·3%	Av. 5·7%	Frequent	Av. 0·8%, frequent
Red clay . .	4285–5082 (av. 4720)	Practically *nil*	..	..	..	Very few *Coscinodiscus*	..	..	..	..	..
Lagoon mud .	27–46 (av. 36)	5·8%	11 spp.	28 spp.	4 spp.	..	..	Few only			
Lagoon sand .	31–57 (av. 45)	53·0%	..	36 spp., 10 only as in lagoon mud	1 sp.	..	..	Very common			..
Outer reef slope deposits . .	101–1280 (av. 523)	57·4%	15 spp.	80 spp. lagoon, shallow water, and gl. ooze spp.	15 spp.	..	..	L.=<2% G.=*c*.7%	<1·0%	Few	Few otoliths

Cr. virgula.	*Cavolinia gibbosa.*
Hyalocylis striata.	*C. globulosa.*
Clio cuspidata.	*C. longirostris.*
Cl. pyramidata.	*C. uncinata.*
Cuvierina columnella.	*Atlanta* sp.
Diacria quadridentata.	Otoliths.

(j) *Summary of the Composition of the Deposit Types.*

Table XIII summarizes the depth distribution and composition of the various deposit types discussed in the foregoing pages.

(k) *The Effect of the Deposit Type on the Fauna.*

The type of deposit present appears to have a considerable effect upon the numbers of animals inhabiting an area, as it is hoped to show from the hauls taken with the grab on different types of sediment. The effect is probably due to the potential food value of the deposit as well as to its texture.

Most of the grab samples are green or brown muds and these will be considered first. Animals were obtained at sixteen different depths, representing twenty-two hauls, and varied in numbers from as many as fifty-one downwards. Eleven samples contained more than ten specimens, five less than ten and the remaining six none. If the unproductive hauls are omitted the remainder average about 20 animals per 0·5 sq. m., allowing for those recorded as "few" or "several." For all twenty-two hauls the average is about 14 per 0·5 sq. m. The number of phyla or lesser groups present is low in all hauls—usually between two and four ; even in the haul with fifty-one animals only four groups were represented. Four of the six samples containing no live animals are quite distinct from the others. The bulk of the deposits are green or greenish-brown muds. In two instances hydrogen sulphide was present. One of these samples, from Sta. 77, contained no life, and the other, from Sta. 189, only four organisms. The other five barren samples all came from the Zanzibar Area. One, from Sta. 103, is a sandy, noncoherent green mud, almost classifiable as a muddy sand ; another, from Sta. 113, is a muddy sand. There appears no reason why these deposits should contain no live animals, and the samples are probably not representative of the locality. At Sta. 105 the deposit is a very clayey mud, almost a grey clay, and as has been seen (p. 110), this latter type of deposit seems to support few or no animals. The remaining two barren samples are from Stas. 114 and 125. The deposit at both of these is recorded as a light brown or yellowish mud overlying grey-green mud and grey clay respectively. This light brown mud appears to be peculiarly unable to support animal life. It was found also at Sta. 5 in the Red Sea, and here, again, nothing was caught in the dredge.

The grey-white muds of the Maldive area are capable of supporting a considerable fauna. The number of animals present here is considerably higher than in the majority of examples of green or brown mud, as the following summary of hauls shows :

Station.	Number of animals.	Number of groups present.
137	28	6
142b	40	6
147	30	4
160	42	3
164	38	5
Average	36	5

The number of groups represented is likewise rather higher. This greater abundance of animals in the shallow water of the lagoons is perhaps due to the greater production of vegetable matter in the shallow illuminated waters. This vegetable matter and that derived from land vegetation forms a primary source of food for the plant- and detritus-feeders, and these in turn for the predatory species.

There remain to be considered the coarser deposits, which may for this survey be put into two groups—the sand and rubble deposits of the continental shelf, and the sands and gravels of the Maldives. The latter are separable into coarse lagoon deposits and coarse deposits from deep water on the outer slopes of the atolls.

On the continental shelf there appears to be much less life in these deposits than in the muds. Of five samples, two yielded no animals at all and the other three varied up to twenty. The number of groups represented is fairly high, four and five, but at the third station (Sta. 89) the twelve specimens obtained all belonged to one species of *Cardium*-like Lamellibranch. The records for these stations and the Maldives are tabulated below :

	Station.	No. of animals present.	No. of groups present.
Continental shelf	89	12	1
	90	..	..
	112	"Several"	4
	113	..	..
	178	20	5
Outer slopes of atolls	149	7	6
	150	..	..
	151	7	5
	163	11	3
	165	..	..
Lagoons	139	12	5
	141	31 + "several"	6
	144	22	8
	161	8	6

The fauna on coarse deposits on the slopes of the atolls thus appears to be rather similar in quantity to that from similar deposits on the continental shelf. The sands and gravels of the lagoons, however, obviously support a denser and more varied fauna. This fauna is very different from that of the lagoon muds. It consists chiefly of attached or sedentary animals or actively moving forms such as Crustacea. There are far fewer of the

burrowing and mud-feeding forms present. In other words here the " epifauna " is developed in place of the " in-fauna."

In the following table (Table XIV) the number of times each of the different groups was obtained in each of the four types of deposit is shown. The figures in black type indicate that the animals recorded belong to the epifauna. It is readily seen that the Cœlenterata, except for the Actinians and solitary corals, some of which live in the mud, belong to this attached fauna. They require a solid substratum, and do not occur on a muddy bottom whether this is of continental or coral origin. The solitary corals and perhaps the Actinians, on the other hand, may prefer a mud bottom. The single Actinian recorded, however, is probably an odd epizoic specimen dislodged from its support. Polyzoa were obtained only on the hard coral bottom. In contrast, the Polychæta were obtained no less than fourteen times (out of a possible twenty) in the green and brown muds and five times in the fine white coral muds, but not at all in the coarser sandy deposits.

TABLE XIV.—*Number of Times Different Animals were Obtained by Grab in the Deposits.*

Group.	Green and brown mud.	White mud.	Sandy bottom.	Coral bottom.
Porifera	..	..	**2**	**6**
Hydroids	..	..	..	**2**
Actinians	1	..	..	..
Alcyonacea	..	..	**1**	**1**
Gorgonacea	..	..	**1**	..
Madreporaria (colonial)	..	..	**1**	**1**
Madreporaria (solitary)	2	..	..	**2**
Polyzoa	..	..	..	**1**
Polychæta	14	5	..	..
Sipunculoidea	..	2	..	2
Crustacea (unspecified)	3	..	..	..
Amphipoda	..	1	..	..
Isopoda	1	1	..	..
Stomatopoda	2	3	..	1
Paguridea	..	1	..	1
Galatheidea	..	..	**1**	**1**
Prawns	..	..	**1**	**2**
Brachyura	5	4	**1**	**3**
Asteroidea	1	..	..	..
Ophiuroidea	3	2	..	3
Echinoidea	2	2	..	..
Holothuroidea	2	..	..	1
Mollusca (unspecified)	..	..	..	**1**
Lamellibranchiata	4	1	1	3
Gasteropoda	1	..	..	**2**
Scaphopoda	1	..	..	..
Pteropoda	..	..	1	..
Pisces	..	..	..	**1**
Algæ	..	..	**1**	..

The occurrence of the Sipunculoidea is interesting. These were obtained twice in coral mud and twice in the coarse coral deposits, but not in either of the deposits of the Continental Shelf. Apparently, therefore, it is not so much the fineness of the deposit which affects these animals as its chemical composition, a highly calcareous deposit being preferred to one with less calcium carbonate. It is not a question of these animals being limited to shallow lagoon water, as the above records range from 27 to 274 m., the latter depth being at a station well outside the atoll of Minikoi. It is probable that these animals subsist on coral and coralline algal detritus broken off from the reefs by the action of the surf and boring organisms.

The burrowing Stomatopoda prefer a muddy bottom to one composed of sand or gravel, though in one haul (Sta. 141) a single specimen was obtained from a depth of 44 m. on a gravel bottom. The Isopoda also apparently prefer a muddy bottom, not having been taken on the coarser substrata. On the other hand the Prawns and Galatheidea appear to prefer the coarser deposits, probably as these afford more protection under pebbles and shells and in the growth of attached forms. There is also less mud to clog the gills. Brachyura, on the other hand, were frequently obtained on muds even in the presence of sulphuretted hydrogen. Thus at Sta. 77 the mud smelled strongly of sulphuretted hydrogen and the grab obtained no animals, but the Salpa dredge procured a single specimen of the crab *Parilia alcocki* Wood-Mason. Crabs also occurred frequently on the coarse coral deposits, though only once were they obtained on a sandy terrigenous bottom. None of the crabs have been identified, but it is highly probable that those from the muds will prove to be of very different types to those from the coral bottom, each type preferring its own type of bottom and not encroaching on the domain of the other to any extent. The one set would be adapted for living on or in the mud, whereas the others, adapted for a life above the mud among the corals, hydroids, etc., would be smothered if transferred to a soft mud.

The Echinodermata prefer the mud bottoms to the coarser materials except for the Ophiuroidea which were common on the coarse coral deposits. Here again there are probably two sets of species, one being epizoic forms living on or in sponges, on Gorgonians, hydroids, etc., whereas the others are true bottom-living species dwelling on or in the mud.

With regard to the Mollusca it is not possible to make a definite statement. Both Lamellibranchiata and Gasteropoda were obtained several times on terrigenous mud and on coarse coral bottoms. These may be attached forms of the epifauna present on the hard bottom. On the other hand, the molluscs from the hard bottom may be part of the true mud fauna living in the finer parts of these coarse deposits. A similar condition has been shown by Petersen (1914, p. 16) for Danish waters, where the true in-fauna is present though obscured by a large development of an epifauna—in his instances a mussel-bed. Here the bivalves and Gasteropoda may form the in-fauna with a considerable epifauna of attached forms and commensals, greatly restricting the area available for the mud-dwellers.

V. THE DISTRIBUTION OF VARIOUS REMAINS IN THE DEPOSITS.

The amount of the remains of any of the more commonly occurring groups present in the deposits fluctuates violently over very small depth ranges in shallow waters, indicating that factors other than depth operate to determine the abundance of any group. This fluctuation is well seen in Table XV, showing the percentages of various groups from stations of equal depth.

TABLE XV.

Depth (m.) .	46.		91.			274.				
Station	137.	161.	73.	178.	189.	67.	88.	163.	179b.	191.
Foraminifera . .	tr.	4·4	1·2	0·3	0·3	..	..	1·6	tr.	tr.
Echinodermata . .	0·3	0·1	1·4	0·3	0·1	..	..	0·8	1·9	0·1
Lamellibranchiata .	0·5	3·8	30·0	1·9	6·3	..	0·5	2·1	1·5	1·4
Gasteropoda . .	7·1	6·3	7·8	5·0	15·3	..	0·2	6·8	2·1	0·2
Pteropoda . . .	0·3	..	1·5	tr.	0·4	3·1	0·6	0·3	1·1	0·2
Scaphopoda . . .	..	..	0·1	tr.	0·4	..	..	..	..	0·1
Total% . . .	8·2	14·6	42·0	7·5	22·8	3·1	1·3	11·6	6·6	2·0

These fluctuations cease at about 400 m. and the individual percentages remain relatively constant at about 2·0% or less for the next 300 m. This low percentage over the range 400–700 m. corresponds to the minimum amount of total remains shown in Text-fig. 1 (p. 114), and shows that the minimum in this curve is due to a general reduction in the amount of all groups and not to the absence of one or two. This phenomenon, shown by the fauna, has been pointed out by Hesse (1924, pp. 20, 262), drawing examples from the total number of species collected by the "Challenger", from the species of Ascidians and Brachyura of that expedition and from the Foraminifera collected by the "Gazelle". This general decrease in the amount of animal remains, and therefore of animals, is due to the effect of the increased depth excluding much of the fauna, under uniform conditions of the bottom. In shallow water the effect of depth is largely masked by that of the less uniform nature of the bottom.

The distribution of various remains in the deposits is considered in the following pages.

(a) *Pteropoda.*

The shells of Pteropoda are among the most commonly occurring remains to be found in the sediments of the Arabian Sea. As the sample analyses (section II) show, the percentage weight of the sediments formed by these shells is seldom high. The highest amounts found were 14·2% and 11·2% (Stas. 28 and 75 respectively). Two other localities (Stas. 206, 207) gave 8·0% and 8·1% respectively. These values are all far higher than the normal for this group of remains. The average value is only about 1·0%. Naturally such a low percentage does not give the mud a characteristic appearance, and the shells are usually inconspicuous in intact samples. On sifting the mud, however, the shells are readily distinguishable and may form a considerable portion of the siftings, and in a few cases (Pteropod ooze) may far outnumber and outweigh other remains, which may be very scarce.

Table XVI shows all the species of Pteropoda identified from the sediments, the number of times each was obtained, and the localities where they occurred.

Table XVI.

Species.	Number of times obtained.	Red Sea.	Gulf of Aden.	Gulf of Oman.	South Arabian Coast.	Northern Arabian Sea.	Zanzibar area.	Maldive area.	Number of areas.
Peraclis depressa	2	..	2	..	..	..	..	..	1
P. reticulata	1	..	..	..	1	..	..	..	1
Limacina inflata	20	5	10	1	..	2	..	2	5
L. helicina	2	1	..	1	..	..	..	..	2
L. bulimoides	4	1	3	..	..	..	..	..	2
L. trochiformis	4	1	3	..	..	..	..	..	2
Creseis acicula	37	6	8	3	5	2	7	6	7
Cr. virgula	26	6	7	4	3	2	1	3	7
Hyalocylis striata	21	6	8	3	2	2	..	..	5
Styliola subula	1	..	1	..	..	..	..	..	1
Clio cuspidata	8	..	3	..	..	..	4	1	3
Cl. pyramidata	31	5	10	1	2	2	7	4	7
Cuvierina columnella	7	..	1	..	..	..	6	..	2
Diacria quadridentata	37	6	11	4	4	3	6	3	7
D. trispinosa	6	..	3	..	..	..	3	..	2
Cavolinia gibbosa	6	..	..	..	..	..	6	..	1
C. globulosa	10	3	1	..	..	..	5	1	4
C. inflexa	10	1	3	1	..	..	5	..	4
C. longirostris	47	6	14	5	5	4	7	6	7
C. tridentata	15	1	2	..	..	..	10	2	4
C. uncinata	32	5	9	..	..	3	10	5	5
Total number of species	21	14	18	9	7	8	13	10	..

The above table includes six species not obtained in the plankton hauls, namely:

Peraclis depressa. *Limacina helicina.*
P. reticulata. *Cuvierina columnella.*
Limacina bulimoides. *Cavolinia gibbosa.*

On the other hand one species, *Clio chaptali,* obtained in the plankton hauls, was not identified from the sediments.

Judging by the number of times each was taken, the commonest species appear to be *Cavolinia longirostris, Diacria quadridentata, Creseis acicula, Cavolinia uncinata, Clio pyramidata, Creseis virgula, Hyalocyclis striata* and *Limacina inflata,* in this order. Of these eight, the following occurred in all seven areas given in Table XVI :

Creseis acicula. *Diacria quadridentata.*
Cr. virgula. *Cavolinia longirostris.*
Clio pyramidata.

These are the most widely distributed species in the north-west area of the Indian Ocean. The other three species listed above, *Limacina inflata, Hyalocylis striata* and *Cavolinia uncinata,* occurring in five of the areas, are next in order of distribution. The distribution of the less common species is seen from the table, the last column giving the number of regions in which each species was obtained. The " regions " used here are those given in the " Station List " of the Expedition (Sewell, 1935*b*, p. 17).

It is apparent from the table that the Gulf of Aden is richest in species, but is fairly closely followed by the southern end of the Red Sea and the Zanzibar Area. The remaining areas have less than half the total number of species identified in the deposits, and are thus comparatively poor in species. Except for the Maldive Area, these areas poor in species of Pteropoda are all in the northern part of the Arabian Sea. This is also noticeable in the catches of living Pteropoda. Fewer species were caught in the northern region than from the western side of the Arabian Sea or from the Maldives.

As already stated in the opening paragraphs of this section, the amount of any group in the deposits fluctuates considerably in the upper 400 m., but falls off below this depth. This applies equally to the Pteropoda. Moreover, there is only a small percentage of Pteropod shells in shallow water of less than 150 m. depth. This is probably due to the action of currents, which move the other remains and the sand and grind up the delicate shells of the Pteropoda. Below 150 m. the numbers fluctuate greatly, being very high in Pteropod ooze and green Pteropod muds and low in other green muds. Below 400 m., however, the numbers seem to reach a constant value of rather less than 2% of the deposit—at least down to 700 m.

It is of interest to note that in the Zanzibar Area none of the Limacinidæ were found, nor were the Cavoliniid genera *Hyalocylis* and *Styliola*, but that all the other species listed above occurred at one or more stations.

The occurrence of large numbers of Pteropod shells in the southern part of the Red Sea and in the Gulf of Oman can be correlated with the movements of the several bodies of water in these areas.

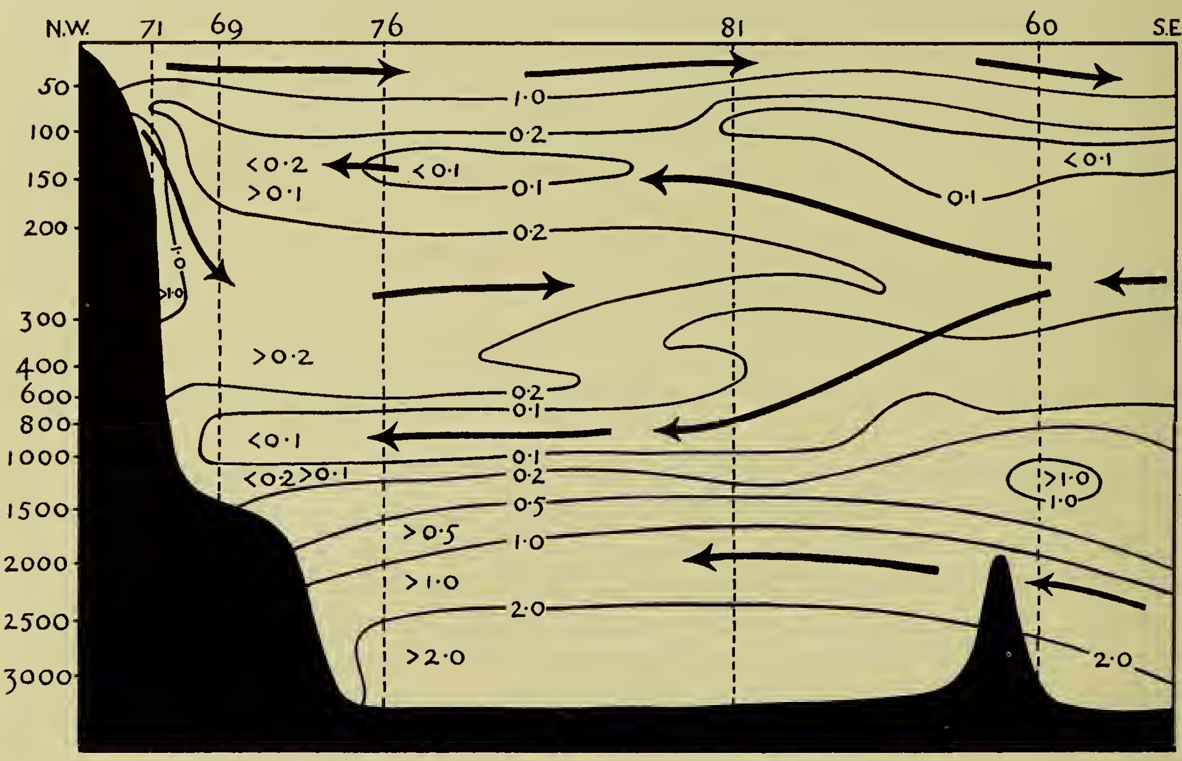
During the summer season there is an outflow of highly saline water, from the Red Sea, over the "sill", into the Gulf of Aden. This outflow is considerably diminished during the winter season, when there is a current of water flowing in the opposite direction. It is probably this Gulf of Aden water that carries the Pteropoda into the Red Sea, where they come into contact with the more saline and warmer Red Sea water, which proves fatal to them. Their shells sink down to form the deposit of Pteropod ooze met with on the north-west side of the "sill". Passing from the Gulf of Aden, over the "sill", into the Red Sea, the percentage of Pteropod shells in the deposit is at first negligible. At the highest point of the "sill" it is just measurable. On its north-west side it rises rapidly, and north of the "sill" reaches 8·0% of the deposit and over 60·0% of the total animal remains. Table XVII shows the available data for the occurrence of Pteropod shells in this region :

TABLE XVII.

Region.	Station.	Deposit.	Pteropod shells. % deposit.	Pteropod shells. % remains.
Gulf of Aden	12	cs. s. sh.	..	..
SE. side of "sill"	9	r., s.	..	..
Top of "sill"	204	gn. m. Pt. sh.	0·4	1·5
NW. side of "sill"	7	s., Pt. sh.	..	16·9
	206	Pt. oz.	8·0	60·5
	207	Pt. oz.	8·1	65·4
Red Sea, north of "sill"	208	gn. m.	..	..
	209	calc. r., Pt. frags.	..	..

It is apparent, therefore, that large numbers of the Pteropoda are killed off on entering the Red Sea and meeting the more saline and warmer water. There is another patch of Pteropod ooze in the middle of the Red Sea, about Lat. 19° N., but none North of this.

The occurrence of Pteropod deposits in the Gulf of Oman can likewise be correlated with the mingling of masses of water of different temperature and salinity. The circulation here is rather similar to that in the Gulf of Aden. Four separate bodies of water occur, as shown in the accompanying figure (Text-fig. 5), which represents a longitudinal section of the Gulf of Oman. At the surface a stream of water of high salinity, temperature and oxygen-content derived from the Persian Gulf is flowing out of the Gulf of Oman. A second and lower body of Persian Gulf water, lying at a depth of 70 m. at the head of the



Text-fig. 5.—The circulation in the Gulf of Oman (after Thompson, unpublished).

Gulf, sinks to 300 m. and also moves out of the Gulf. This water has a high temperature and salinity and is at first moderately well oxygenated ($>1{\cdot}0$ c.c. litre). It rapidly loses its oxygen, which off Muscat has fallen to 0·25 c.c. litre. Both these bodies of water swing to the right out of the Gulf of Oman and flow along close to the Arabian coast. Between them is a mass of poorly oxygenated water of low salinity flowing into the Gulf of Oman from the Arabian Sea. This appears to divide, some of it passing between the two layers of Persian Gulf water and some under the lower layer between it and the bottom water. The latter, lying below 1500 m., is comparatively highly oxygenated and of low salinity. Thus at all depths above 1500 m., except at the surface, the water is poorly oxygenated. Pelagic organisms are brought into the area by the surface Arabian Sea water which sinks below the outflowing Persian Gulf water. The deficiency in oxygen and the increased salinity met with in this Persian Gulf water cause the death of many of these organisms, especially the Pteropoda, whose remains sink down to accumulate in the deposit. The change in conditions

is probably not very abrupt, as no great number of Pteropoda are found in the deposits until the north-west end of the Gulf of Oman is reached. Here a small patch of Pteropod ooze occurs at Sta. 75. It is, of course, at this end of the Gulf that the difference between the inflowing and outflowing bodies of water is most marked.

The formation of Pteropod ooze on the Bombay shelf, recorded by the R.I.M.S. "Investigator", may also be due to a sudden change in the hydrographical conditions, perhaps here to a lowering of the salinity by the influx of fresh water from the Gulf of Cambay.

Along the African coast a similar fatal change in conditions is probably brought about by the upwelling of cold deeper water during the south-west monsoon.

(b) *Vertebrate Remains.*

Vertebrate remains were found at fifty-three stations, the most commonly occurring remains being fish otoliths, mainly of a uniform, very small size. Only occasionally were otoliths more than 5·0 mm. in length obtained. Otoliths occurred at forty-one of the fifty-three stations. Other Teleost remains were taken at a number of stations. Bones occurred in nineteen hauls and scales in nine. Among the latter, two hauls yielded triradiate spines, presumably scales of *Diodon* or a similar spinous form. Among the bones, vertebræ were commonest, ranging in size up to 24 mm. across the centrum. Other identifiable bones were ribs, opercular, dentary, premaxilla, maxilla and symplectic of various species. Of other fish remains, sharks' teeth occurred twelve times. These were mainly small teeth from the Priestman grab samples from comparatively shallow water—less than 400 m. No teeth coated with a thin layer of manganese, such as are figured by Murray and Renard (1891, pls. v–viii), were found, and no ear bones or beaks of whales. A few teeth, forming the nuclei of manganese nodules, were found at Sta. 166. The following genera of sharks* are represented, the figures in brackets indicate the number of teeth found :

Family Lamnidæ.
- *Isurus* sp.
  - Sta. 54 (1).
  - Sta. 176 (1).
  - Sta. 193 (1).

Family Carcharinidæ.
- *Aprionodon* sp.
  - Sta. 207 (2).
- *Scoliodon* sp.
  - Sta. 56 (2).
  - Sta. 57 (2).
  - Sta. 207 (1).
- *Carcharinus* sp.
  - Sta. 34 (1).
  - Sta. 56 (1).
  - Sta. 57 (2).
  - Sta. 59 (1).
  - Sta. 86 (3).
  - Sta. 176 (3).
  - Sta. 207 (2).
- ? *Carcharinus* sp.
  - Sta. 75 (1).
  - Sta. 89 (1).
  - Sta. 179b (1).

In addition a Teleost tooth, probably of a species of *Evermannella*, was identified from Sta. 78.

Other remains include a large egg-case of a species of ray from Sta. 120 and a turtle scale from Sta. 153.

* Identifications by Mr. J. R. Norman, Brit. Mus. (Nat. Hist.).

The more commonly occurring remains, otoliths, bones, scales and sharks' teeth have similar depth ranges. The following are the extremes of depth recorded for each type of remains :

Otoliths (31, 37), 91–2312 m.	Scales 201–1061 m.
Bones (37), 102–1269 m.	Sharks' teeth, 101–3351 m.

The figures in brackets indicate the depths at which the remains were found in the lagoons of the Maldive Archipelago. The wide depth range of otoliths is in agreement with Murray's conclusion (1891, pp. 267–8) that these are the most resistant of the calcareous structures of fish, but he does not record scales from any of the materials of the " Challenger " expedition. Bones, other than beaks and ear-bones of whales, were only obtained on three occasions. On the other hand he records teeth as " exceptionally abundant " in the pelagic deposits, especially in red clay, whereas at no station in the north-west Indian Ocean were sharks' teeth very common and none were obtained from red clay, the chief source of those obtained by the "Challenger", except those forming the nuclei of manganese nodules. Agassiz (1888, p. 281) comments on the unusual number of otoliths found in deposits from the Gulf of Mexico in depths from 392–1568 fms. (725–2900 m.). Fish teeth also occurred here in some deposits from over 500 fms. (925 m.).

(c) *Siliceous Remains.*

(c. i) *Porifera.*—Siliceous remains are rather rare in the deposits and consist of Diatoms, fragments of sponge spicules and Radiolaria. Sponge spicules occurred most frequently, being found at thirty-three stations. At Sta. 175 only were they abundant in green calcareous mud from 1618 m. At three other stations spicule fragments were fairly common, as follows :

Station.	Depth (m.).	Deposit.
119	1204	lt. br. clayey, gl. oz.
135	2727	gl. oz.
152	878	gy. m.

Fragments of Poriferan skeletons were only of rare occurrence at the remaining twenty-nine stations. The rarity of sponge spicules may be due to the physical state of the silica. According to Pirrson (1920, p. 433) this is in the colloidal form, and is readily destroyed during organic decay and seldom preserved as a fossil. He says that Radiolaria and Diatoms, however, are composed of silica in an insoluble form and are rarely destroyed. Nevertheless, Radiolaria and Diatom frustules are by no means as common as siliceous sponge spicules in the deposits. Sponge spicules are present over a wide depth range, as the following figures show :

Metres.	No. of records.	Metres.	No. of records.
0–500	5	3000–4000	2
500–1000	5	4000–5000	5
1000–2000	8	Over 5000	1
2000–3000	7		

It is noticeable that most of the records occur at the mouth of the Gulf of Aden or in the Zanzibar region and very few in the open sea.

(c.ii) *Radiolaria.*—Radiolaria were identified in sediments from nineteen stations, ranging in depth from 1173–4499 m. The distribution in depth is shown below :

Metres.	No. of records.	Metres.	No. of records.
0–1000	..	3000–4000	2
1000–2000	6	4000–5000	6
2000–3000	5		

Radiolaria appear to be entirely absent from the shallower deposits. In those from below 1000 m. they occur very sparingly. At no station were they found in sufficient numbers to form a deposit that could be called Radiolarian ooze : even in the South Somali Basin, in which Murray and Philippi (1908, p. 167) record a large area of the bottom as covered with Radiolarian ooze, none were obtained. There are no Radiolaria in the pure red clay obtained in the Arabian Basin at Sta. 166, though a few were found in the transitional Globigerina ooze from the next station, Sta. 167.

It is of interest that no less than nine of the records of Radiolaria lie in or about the mouth of the Gulf of Aden and only one in the western part of the Gulf. The other nine records are scattered about the southern and central regions of the Arabian Sea. No records come from the Oman Basin, and only two from the extreme southern border of the Arabian Basin, one (Sta. 167) near the Carlsberg Ridge and the other (Sta. 135) on the western slope of the Maldive ridge.

(c. iii) *Diatoms.*—Diatom frustules were found in the sediments from fifteen stations dotted about the Arabian Sea. Like the other siliceous remains diatoms are not generally common, but in several places they are abundant. Thus, off the mouth of the Gulf of Aden, Diatom frustules were quite common at Stas. 22, 39 and 175, and off Ras al Hadd were abundant in green mud from Stas. 55 and 56. The Diatoms from these two stations were all of one species, the large circular *Coscinodiscus oculis-iridis* var. *borealis* (Bail.), Cl. Fragments of this or other *Coscinodiscus* spp. were the chief forms present at most of the other thirteen stations where diatom frustules were found. At the remaining ten stations Diatoms were very rare.

Diatom remains occur more frequently on the western side of the Arabian Sea than elsewhere as the following figures show :

African and Arabian coastal regions.	Central Arabian Sea.	Eastern Arabian Sea.
11 Stas.	1 Sta.	3 Stas.

As already stated (p. 120), *Coscinodiscus* spp. occur abundantly in the surface waters of the northern Indian Ocean. The more frequent occurrence of these diatoms in the deposits on the western side of the Arabian Sea can probably be correlated with increased productivity due to the transport of nutrient salts to the surface by upwelling water along the African and Arabian coasts during the south-west monsoon.

(d) *Bottom-living Mollusca.*

The bottom-living Mollusca are represented in the sediments by shells and shell-fragments of Gasteropoda, Lamellibranchiata and Scaphopoda. The last, however, are

rather rare and usually negligible as components of the sediments. They were found in only fourteen samples. Table XVIII gives an idea of the relative importance of the three groups of Mollusca as components of the sediments :

TABLE XVIII.

	Gasteropoda.	Lamellibranchiata.	Scaphopoda.
Number of records.	67.	60.	14.
Maximum % of lagoon sediments	21·4	13·5	..
Average % of lagoon sediments	6·4 (9 Stas.)	4·0 (9 Stas.)	..
Maximum % in deep water	16·0	30·0	2·6
Average % in deep water	3·9 (24 Stas.)*	4·8 (23 Stas.)*	0·8 (12 Stas.)*
Average % in deep water (excluding abnormal values)	2·8	2·1	0·8

* Incomplete samples or negligible quantities made averaging impossible at the other stations.

The above table indicates that generally the Gasteropoda and Lamellibranchiata contribute about equally to the deposit. Either, however, may be entirely absent or vastly in excess of the other, attaining as much as 15–20% of the deposit (Gasteropoda) or even 30% (Lamellibranchiata). The contributory value of each group varies in the lagoons and in deep water. Comparing the two more important groups, Gasteropoda and Lamellibranchiata, these contribute about equally to the deep-water deposits. In the lagoons, however, the Gasteropoda apparently contribute about half as much again as the Lamellibranchiata. Although both Gasteropoda and Lamellibranchiata are generally present, the actual percentage contributed by either to the deposit is usually low. The deposits from the following stations only contained more than 5% of shells :

Stations with 5% or more of—

Lamellibranchiata.		Gasteropoda.		
28	142a	28	142a	178
72	144	73	144	189
73	189	75	163	190
103	190	139	164	...

These stations occur in groups in several parts of the Arabian Sea. Stas. 72, 73 and 75 are all at the north-western end of the Gulf of Oman ; Stas. 28, 178, 189 and 190 are in the Gulf of Aden ; Stas. 139, 142a, 144, 163 and 164 in the Maldive Archipelago ; and Sta. 103 off Zanzibar. These four regions appear to be the most prolific as regards the production of Mollusca.

The Gasteropoda appear to contribute their maximum to the sediments in the lagoons, where the sands may contain large quantities of Gasteropod fragments. In deeper water the amount falls to only about three-fourths of this. The Lamellibranchiata, on the other hand, show the reverse. In deep water they may form large banks of shells or shells with mud, in which the shells may exceptionally form 30% of the deposit. But in the lagoons the

bivalve portion falls to less than half of this value, the maximum found in the Maldive samples being only 13·5%, as compared with 30·0% for the open waters of the Arabian Sea.

All three groups of Mollusca are most abundant in depths from 200–300 m., though they extend over varying depth ranges. Table XIX shows the depth range of the three groups as deduced from the depths from which the sediments containing them were obtained:

TABLE XIX.

Depth (m.).	Number of times obtained.		
	Gasteropoda.	Lamellibranchiata.	Scaphopoda.
0–100	6	5	2
100–200	8	8	2
200–300	17	16	5
300–400	9	7	2
400–500	2	3	..
500–600	1	2	1
600–700	2	2	2
700–800	2	..	..
800–900	1	1	..
900–1000	1	..	..
1000–1100	1	..	..
1100–1200	2	1	..
1200–1300	1	4	..
↓	↓	↓	↓
2300–2400	1	1	..
↓	↓	↓	↓
3300–3400	1	1	..

It is apparent from the above figures that the Gasteropoda and Lamellibranchiata have much the same bathymetrical range, whereas the Scaphopoda are confined to lesser depths. The maximum occurrence about 200–300 m. is in agreement with the results obtained for the depth distribution of the living Mollusca taken in the grab, namely 160–240 m. (see Text-fig. 3, p. 123).

In most localities the shell remains are much broken and consist of fragments of numerous species. At several stations, however, the shells are almost entirely of one species. At Stas. 180, 190 and 191 the shell component was almost exclusively formed of valves of the Lamellibranch *Venus torresiana* (Smith). This shell was also present in the deposit at Stas. 28, 178, 179b and 192, where, however, it was much less common. Large numbers of the valves had a small round hole bored through them, presumably by a carnivorous Gasteropod.

The size of these valves is fairly uniform. At Sta. 191 most are about 13 m. long, which is nearly the largest size found at any station. At Sta. 180 several sizes of shell are common. These sizes are intermediate between those found at Sta. 191, and those at Sta. 190 where all are rather small, between 7 and 8 mm. long. The presence of a standard size of shell seems to indicate that the bivalves are in most cases killed off *en masse* by unfavourable

conditions rather than by predatory animals. This is borne out by the small number of bored valves, amounting to only about 13·6% of the living animals. Among the small shells from Sta. 190 very few are bored, equivalent to only about 15·2% of the living animals. It is, of course, possible that a plague of predatory animals such as Asteroids may have caused the wholesale destruction of an age-group of the mollusca.

In the case of the mixed sizes of shells from Sta. 180, the bored valves are equivalent to 74% of the living animals, leaving only 26% that have presumably been killed by animals other than boring Gasteropoda or have died from other causes. It seems that the carnivorous Gasteropoda are the chief agents in killing off the Lamellibranchiata, accounting for almost three times as many as are killed by other means at this station.

(e) *Foraminifera.*

Tests of Foraminifera occur in practically all the deposits examined. Close on 300 species and a few varieties have been identified, of which only sixteen species are pelagic. As a general rule the benthic species are commonest in relatively shallow water, i. e. the zone of green mud and sand and the lagoons and slopes of the atolls, though a number occur in the deep water deposits. The pelagic species are commonest in Globigerina ooze, in which the lack of variety is made up for by the great abundance of individual species, *e. g. Globigerina bulloides* and *Globorotalia menardii*. Pelagic species occur in the shallow water deposits, but in smaller numbers. Where the Globigerina ooze passes into green mud, pelagic Foraminifera are common. As the depth at which the green mud lies decreases the number of pelagic specimens decreases, until finally, in the sandy green muds from 100 m. or less, only occasional isolated tests of *Globigerina* may be found.

The tabular summary of the deposit-types in Section IV (Table XIII, p. 140) shows the number of species in each of the deposits. The Foraminiferal faunas of the several deposits have been given in that section and need not be repeated. The following table (Table XX) shows the numbers of species in each deposit that also occur in each of the others.

Comparing the numbers of species found in each deposit, it is obvious that the green muds are the zone in which species production has been most active. More than twice as many species occurred in this deposit as in any other.

Apart from the grey clay, in which the number of species and specimens is very low, the percentage of species peculiar to each deposit is relatively constant, varying from 16·7% in Pteropod ooze to 35·4% in green mud. The greatest number of indigenous species occurs in green mud, which deposit contains by far the most abundant Foraminiferal fauna. Owing to this great abundance, 50–70% of the species found in the other deposits are found here. The actual valves found are shown in Table XX. The number of species common to any two deposits is further increased by the fact that there is no definite line of demarcation between the deposits, which pass into one another, so that some species may be assigned equally to two or more deposit types.

It is noteworthy that the green muds have the greatest number of species in common with the deposits on the slopes of the Maldive atolls, almost 70% of the species found in the "slope" deposits occurring in the terrigenous muds. Apparently depth is a more potent factor in determining the distribution of the species than the type of deposit.

It has already been seen that the Pteropod ooze in the Arabian Sea lies in the transition zone between green mud and Globigerina ooze. The Foraminiferal fauna reflects this :

TABLE XX.

Deposit.	Number of spp.	Number and % of spp. peculiar to deposit.	Number and % of species occurring in other deposits.								
			Grey clay.	Grey mud.	Green mud.	Terrigenous sand.	Globigerina ooze.	Pteropod ooze.	Lagoon mud.	Lagoon sand.	Reef slopes.
Grey clay	8	0 0%	. . . .	1 12·5%	5 62·5%	1 12·5%	2 25·0%	6 75·%	0 0%	0 0%	3 37·5%
Grey mud	28	8 28·5%	1 3·6%	. . . .	17 60·7%	6 21·4%	11 39·2%	3 10·7%	1 3·6%	0 0%	6 21·4%
Green mud	192	68 35·4%	5 2·6%	17 8·8%	. . . .	48 25·0%	36 18·7%	41 21·3%	15 7·8%	18 9·3%	55 28·6%
Terrigenous sand	86	28 32·5%	1 1·2%	6 7·0%	48 55·8%	. . . .	12 14·0%	17 19·7%	10 11·6%	17 19·7%	34 39·4%
Globigerina ooze	61	20 32·7%	2 3·3%	11 18·0%	36 59·0%	12 19·6%	. . . .	8 13·1%	2 3·3%	2 3·3%	17 27·9%
Pteropod ooze	60	10 16·7%	6 10·0%	3 5·0%	41 68·3%	17 28·3%	8 13·3%	. . . .	7 11·6%	6 10·0%	15 25·0%
Lagoon mud	28	5 17·8%	0 0%	1 3·6%	15 53·5%	10 35·7%	2 7·1%	7 25·0%	. . . .	10 35·7%	14 50·0%
Lagoon sand	36	8 22·2%	0 0%	0 0%	18 50·0%	17 47·2%	2 5·5%	6 16·6%	10 27·7%	. . . .	24 66·6%
Outer Reef slope deposits	80	14 17·5%	3 3·75%	6 7·5%	55 68·8%	34 42·5%	17 21·3%	15 18·75%	14 17·5%	24 30·0%	. . . .

The Interrelationship of the Foraminiferal Faunas of the Deposits.

68·3% of the Pteropod ooze species are identical with green mud species. In the Globigerina ooze the percentage in common has fallen to 59.

Very little can be deduced as regards the distribution of individual species, since the majority occurred only once or twice and usually in very small numbers. An idea of this paucity of records can be gathered from the table of species present in green mud (Table V, p. 116). Most of the species listed there occurred only once or twice. The same applies equally to the other deposits. At two stations only was a species taken in really large numbers. *Rhabdammina abyssorum* M. Sars was found at seven stations as follows :

Sta. 50, Arabian coast,
Stas. 26, 185, 188, Gulf of Aden.
Stas. 109, 119, 120, Zanzibar Area.

At Stas. 120 and 185 the variety *radiata* Cushman occurred with the typical form. At six of these stations the species was not common, but at Sta. 185 it was exceedingly abundant. The residue left after washing out the mud from a sample of the deposit consisted almost entirely of fragments of the tests of *Rhabdammina* (see Pl. IV, fig. 2).

At Sta. 105, in the Zanzibar Area, a second arenaceous species, *Dendrophrya ramosa* Cushman, was obtained in equally large numbers. The washed residue again consisted almost entirely of the one species (see Pl. IV, fig. 1). This species was only obtained once more, at Sta. 119, also in the Zanzibar Area.

Presumably the species in both instances has met with optimum environmental conditions. The factor permitting this great development is probably the nature of the bottom. The deposit, though still referable to the same deposit-type, may vary considerably in texture and value as a source of food over small distances. The hydrographical conditions, on the other hand, are relatively stable over much larger areas, and so are unlikely to be the major factor in controlling the development of these " Foraminifera-beds ".

VI. SUMMARY.

1. 185 samples of deposits from 131 stations in the Arabian Sea are described. The distribution of the main types of Marine Deposits in the Arabian Sea is determined from earlier charts and these new materials. The transitional Globigerina ooze/red clay deposit is indicated separately on the new chart, as this mixed deposit is frequently difficult to assign to one or the other of its component types.

The extent of the various deposits in the region of Zanzibar is shown in detail on a separate chart and is discussed. The distribution of the pelagic deposits here is correlated with water movements.

2. The remains of organisms in the deposits have been separated out, and the percentage of remains of each of the commoner phyla determined. The total percentage of remains in the deposits is correlated with the depth, being high in shallow water, low in 500–600 m. and then rising again in about 1000 m. This rise is mainly due to the accumulation of *Globigerina* and other pelagic Foraminiferal shells at this depth. The Foraminifera and Pteropoda are identified. Other organisms are only classed into the appropriate phylum or order or occasionally genus.

3. The samples of deposits and their contained animals collected with the Priestman grab are discussed at length. The shallow-water samples from the lagoons of the Maldive Archipelago are considered separately. There is a steady falling off in the density of the

population as the depth in the lagoon increases. The zonation of the fauna on the Continental Shelf, described by Alcock off the Ganjam coast, is present in the Arabian Sea.

4. The depth range of the animals obtained by the grab is discussed. Lamellibranchiata, Gasteropoda, Ophiuroidea, Prawns, *Upogebia* sp., Corals and Polychæta all have a large vertical range. The greatest number of forms occurred in 160–240 m. This depth is in agreement with that given by Alcock. This is the " mud-line " of Murray.

5. The different types of deposit are reviewed as animal habitats in the light of the grab hauls. Green muds are rich life areas : grey muds and clays and light-brown or yellow muds are almost azoic. Muds and sands from the lagoons are rich in life. Continental sandy deposits support fewer animals than deposits of similar texture from the Maldive lagoons. The occurrence of different groups on terrigenous muds and sands and the muds and sands of the Maldives is tabulated. Certain groups are clearly shown to live mainly or exclusively on the coarser deposits.

6. The distribution of Pteropoda, Vertebrate remains, Siliceous organisms, bottom-living Mollusca and Foraminifera is discussed. The distribution of Pteropod deposits is correlated with peculiarities in the hydrographical conditions.

The relationships of the benthic Foraminiferal faunas of the various deposit types are discussed in general terms. Green and brown muds have the largest Foraminiferal fauna. Over 50% of the species present in Pteropod ooze and Globigerina ooze are found in these deposits. The numbers and percentages of species common to any two deposits and those peculiar to each deposit are tabulated.

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DESCRIPTION OF PLATE I.

1. Grey Mud : Sta. 85, off Bombay, × 15.
    1. *Globigerina bulloides* d'Orbigny.
    2. *Globigerinoides sacculifera* (Brady).
    3. *Orbulina universa* d'Orbigny.
    4. *Pulleniatina obliquiloculata* (Parker and Jones).
    5. *Globorotalia menardii* (d'Orbigny).
    6. *Trochammina globigeriniformis* (Parker and Jones).
    7. Otolith.
    8. Mud lumps.

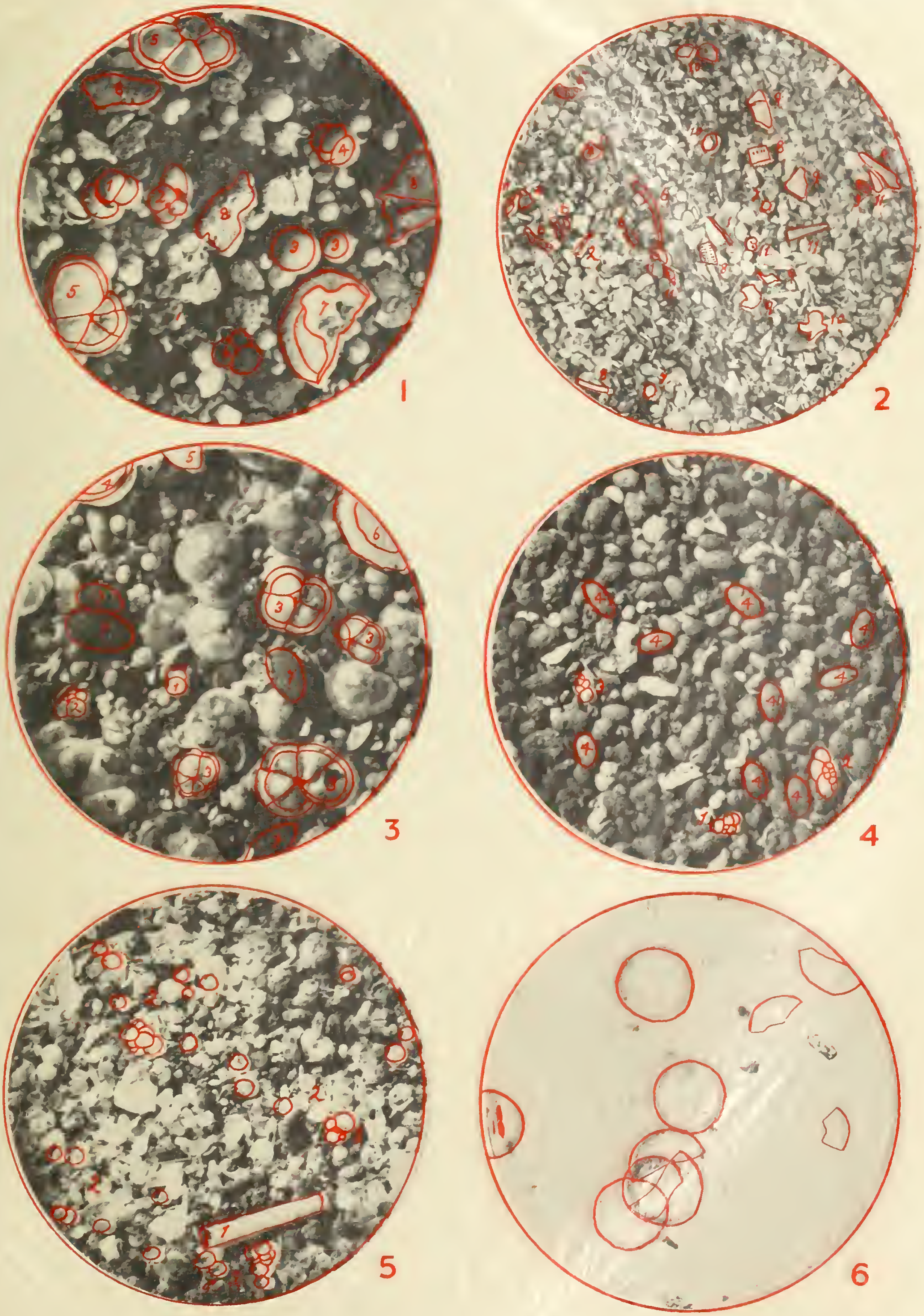
2. Green Mud from shallow water : Sta. 74, Gulf of Oman, × 1.
    1. *Creseis acicula* Rang.
    2. *Cr. virgula* Rang.
    3. *Diacria quadridentata* (Lesueur).
    4. *Cavolinia longirostris* (Lesueur).
    5. Coral fragment.
    6. Polychæt tubes.
    7. Polyzoa.
    8. Echinoderm fragments.
    9. Crustacean fragments.
    10. Lamellibranchiata.
    11. Gasteropoda.

3. Green Mud from deep water : Sta. 20, Gulf of Aden, × 15.
    1. *Globigerina bulloidcs* d'Orbigny.
    2. *Gl. dubia* Egger.
    3. *Globorotalia menardii* (d'Orbigny).
    4. *Pyrgo depressa* (d'Orbigny).
    5. *Creseis acicula* Rang.
    6. Otolith.
    7. Fæcal pellets.

4. Fæcal pellets from Green Mud : Sta. 18, Gulf of Aden, × 15.
    1. *Globigerina bulloides* d'Orbigny.
    2. *Globorotalia canaricnsis* (d'Orbigny).
    3. *Uvigerina* sp.
    4. Fæcal pellets.

5. Diatomaceous Green Mud : Sta. 55, off Ras al Hadd, × 15.
    1. *Creseis acicula* Rang.
    2. *Coscinodiscus oculis-iridis* var. *borealis* (Bail.) Cl.
    3. *Globigcrina bulloides* d'Orbigny.

6. *Coscinodiscus oculis-iridis* var. *borealis* (Bail.) Cl. Specimens × *c.* 65.



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DESCRIPTION OF PLATE I.

1. Grey Mud : Sta. 85, off Bombay, × 15.
   1. *Globigerina bulloides* d'Orbigny.
   2. *Globigerinoides sacculifera* (Brady).
   3. *Orbulina universa* d'Orbigny.
   4. *Pulleniatina obliquiloculata* (Parker and Jones).
   5. *Globorotalia menardii* (d'Orbigny).
   6. *Trochammina globigeriniformis* (Parker and Jones).
   7. Otolith.
   8. Mud lumps.

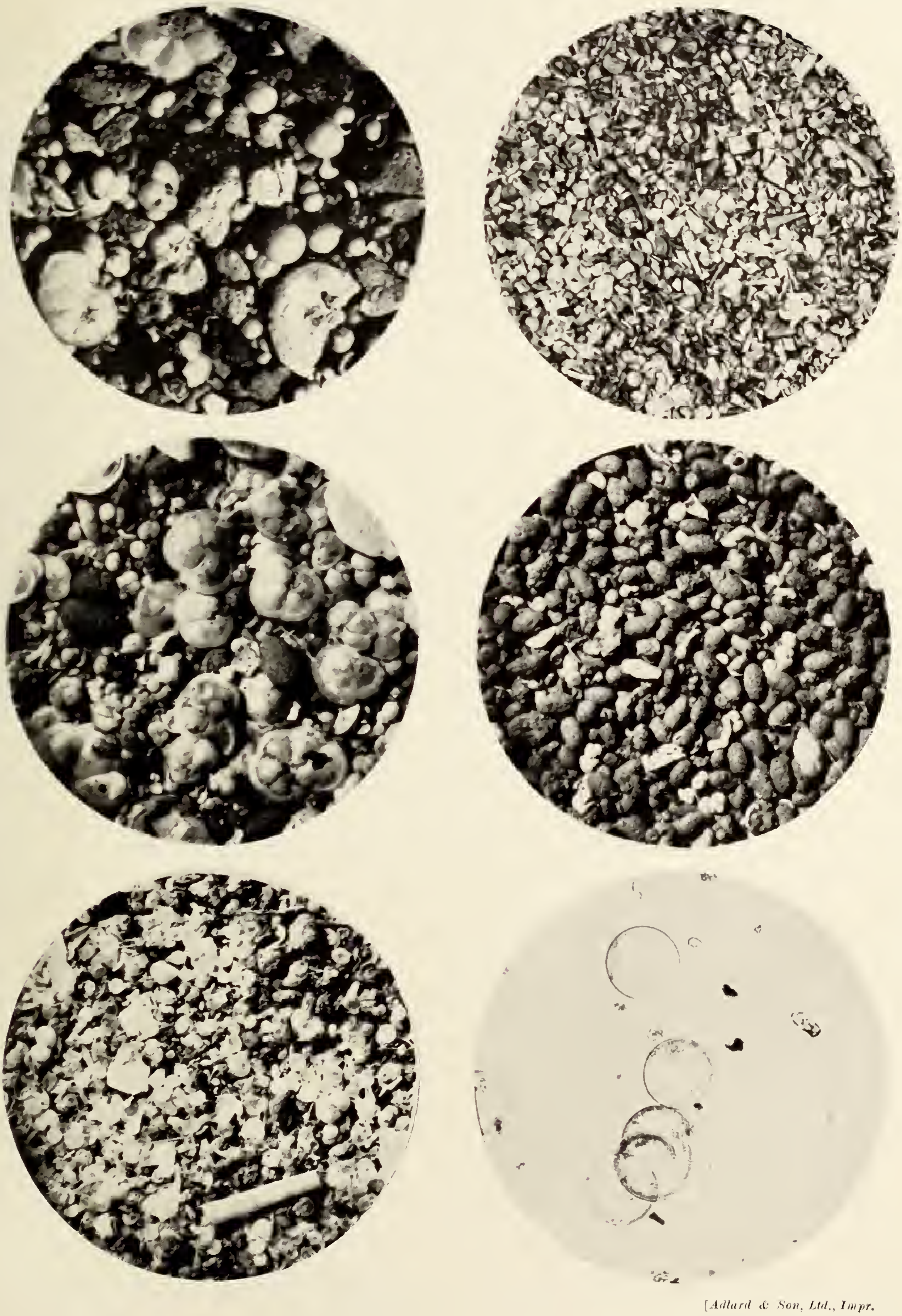
2. Green Mud from shallow water : Sta. 71, Gulf of Oman, × 11.
   1. *Creseis acicula* Rang.
   2. *Cr. virgula* Rang.
   3. *Diacria quadridentata* (Lesueur).
   4. *Cavolinia longirostris* (Lesueur).
   5. Coral fragment.
   6. Polychæt tubes.
   7. Polyzoa.
   8. Echinoderm fragments.
   9. Crustacean fragments.
   10. Lamellibranchiata.
   11. Gasteropoda.

3. Green Mud from deep water : Sta. 20, Gulf of Aden, × 15.
   1. *Globigerina bulloides* d'Orbigny.
   2. *Gl. dubia* Egger.
   3. *Globorotalia menardii* (d'Orbigny).
   4. *Pyrgo depressa* (d'Orbigny).
   5. *Creseis acicula* Rang.
   6. Otolith.
   7. Fæcal pellets.

4. Fæcal pellets from Green Mud : Sta. 18, Gulf of Aden, × 15.
   1. *Globigerina bulloides* d'Orbigny.
   2. *Globorotalia canariensis* (d'Orbigny).
   3. *Uvigerina* sp.
   4. Fæcal pellets.

5. Diatomaceous Green Mud : Sta. 55, off Ras al Hadd, × 15.
   1. *Creseis acicula* Rang.
   2. *Coscinodiscus oculis-iridis* var. *borealis* (Bail.) Cl.
   3. *Globigerina bulloides* d'Orbigny.

6. *Coscinodiscus oculis-iridis* var. *borealis* (Bail.) Cl. Specimens × c. 65.



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DESCRIPTION OF PLATE II.

1. Foraminifera from Green Mud : Sta. 190, Gulf of Aden, × 15.
    1. *Uvigerina pygmæa* d'Orbigny.
    2. *Uvigerina* sp.
    3. Miliolid sp.
    4. *Nonion boueanum* (d'Orbigny).
    5. *Globigerina bulloides* d'Orbigny.

2. Calcareous Terrigenous Sand : Sta. 178, Gulf of Aden, × 1.
    1. Lamellibranch valve.
    2. Gasteropod fragment.
    3. Echinoderm fragments.
    4. Crustacean fragment.
    5. Cirriped valves.
    6. *Heterostegina* sp.
    7. Poriferan spicule.

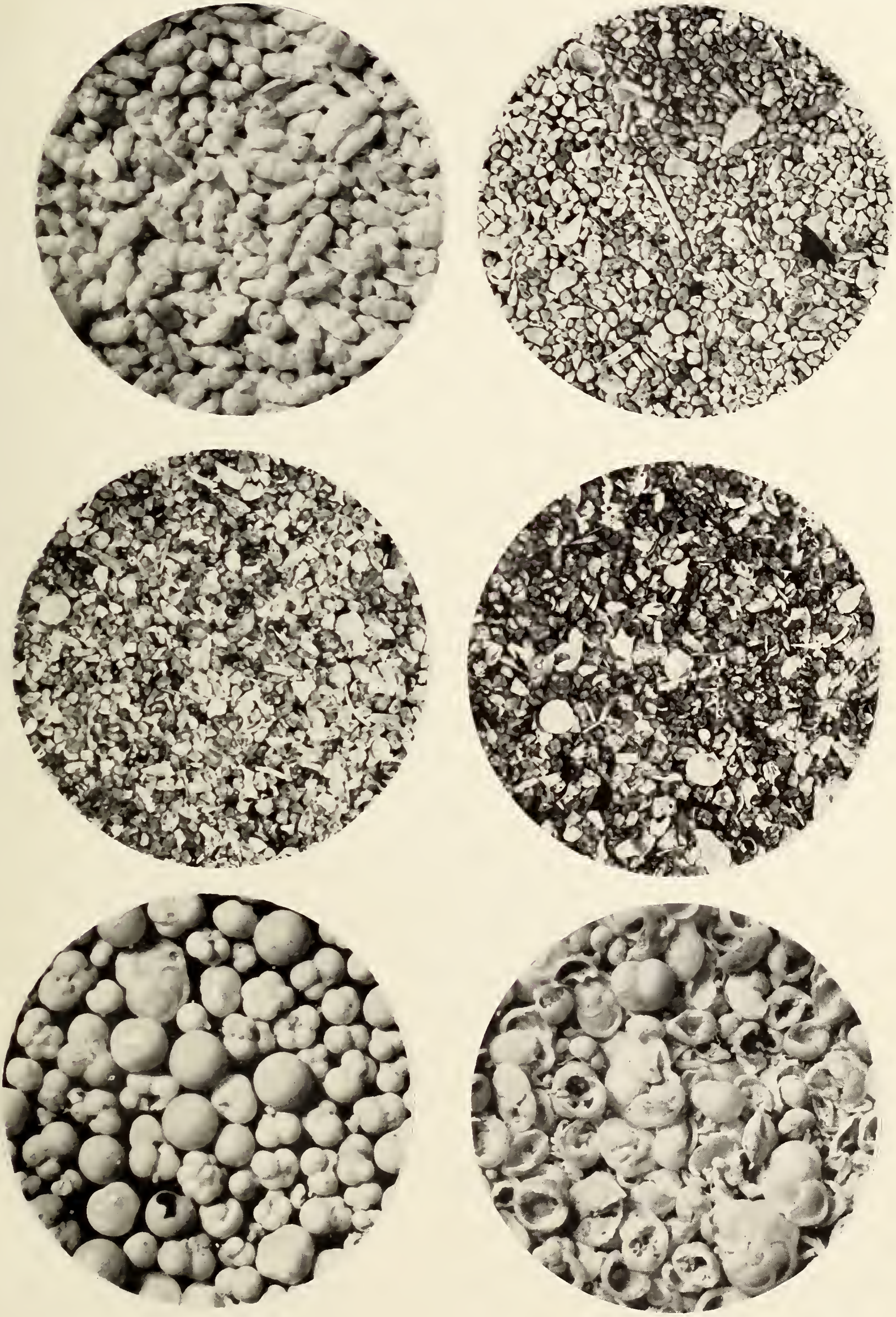
3. Calcareous-Siliceous Sand : Sta. 103, off Zanzibar Island, × 1.
    1. Lamellibranch valves.
    2. Gasteropod fragments.
    3. Echinoderm fragment.
    4. *Nodosaria* sp.
    5. Solitary Coral.
    6. Pteropod shells.
    7. Polyzoa.
    8. Scaphopod shell.
    9. *Miniacina miniacea* (Pallas).

4. Siliceous Sand : Sta. 113, between Pemba Island and Mainland, × 1.
    1. Lamellibranch valves.
    2. Pteropod shells.
    3. Foraminiferan, *Heterostegina* sp.
    4. Crustacean fragment.

5. Globigerina Ooze : Sta. 60, Northern Arabian Sea, × 15.
    1. *Orbulina universa* d'Orbigny.
    2. *Globorotalia menardii* (d'Orbigny).
    3. *Pulleniatina obliquiloculata* (Parker and Jones).
    4. *Sphæroidinella dehiscens* (Parker and Jones).
    5. *Globigerina bulloides* d'Orbigny.
    6. *Gl. dubia* Egger.
    7. *Globigerinoides sacculifera* (Brady).

6. Globigerina Ooze : Sta. 167, Central Arabian Sea, × 15.
    1. *Orbulina universa* d'Orbigny.
    2. *Globorotalia menardii* (d'Orbigny).
    3. *Gl. tumida* (Brady).
    4. *Sphæroidinella dehiscens* (Parker and Jones).

PLATE II.



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DESCRIPTION OF PLATE III.

1. Pteropod Ooze, chiefly *Cavolinia longirostris* : Sta. 207, Red Sea, × 1.
    1. *Cavolinia longirostris* (Lesueur).
    2. *C. uncinata* (Rang).
    3. *Diacria quadridentata* (Lesueur).
    4. *Clio pyramidata* Linnæus.
    5. *Hyalocylis striata* (Rang).
    6. *Creseis virgula* Rang.
    7. *Cr. acicula* Rang.
    8. *Atlanta* sp.
    9. Lamellibranch valves.
    10. Gasteropod shells.
    11. Echinoderm shells.
    12. Fish scale.

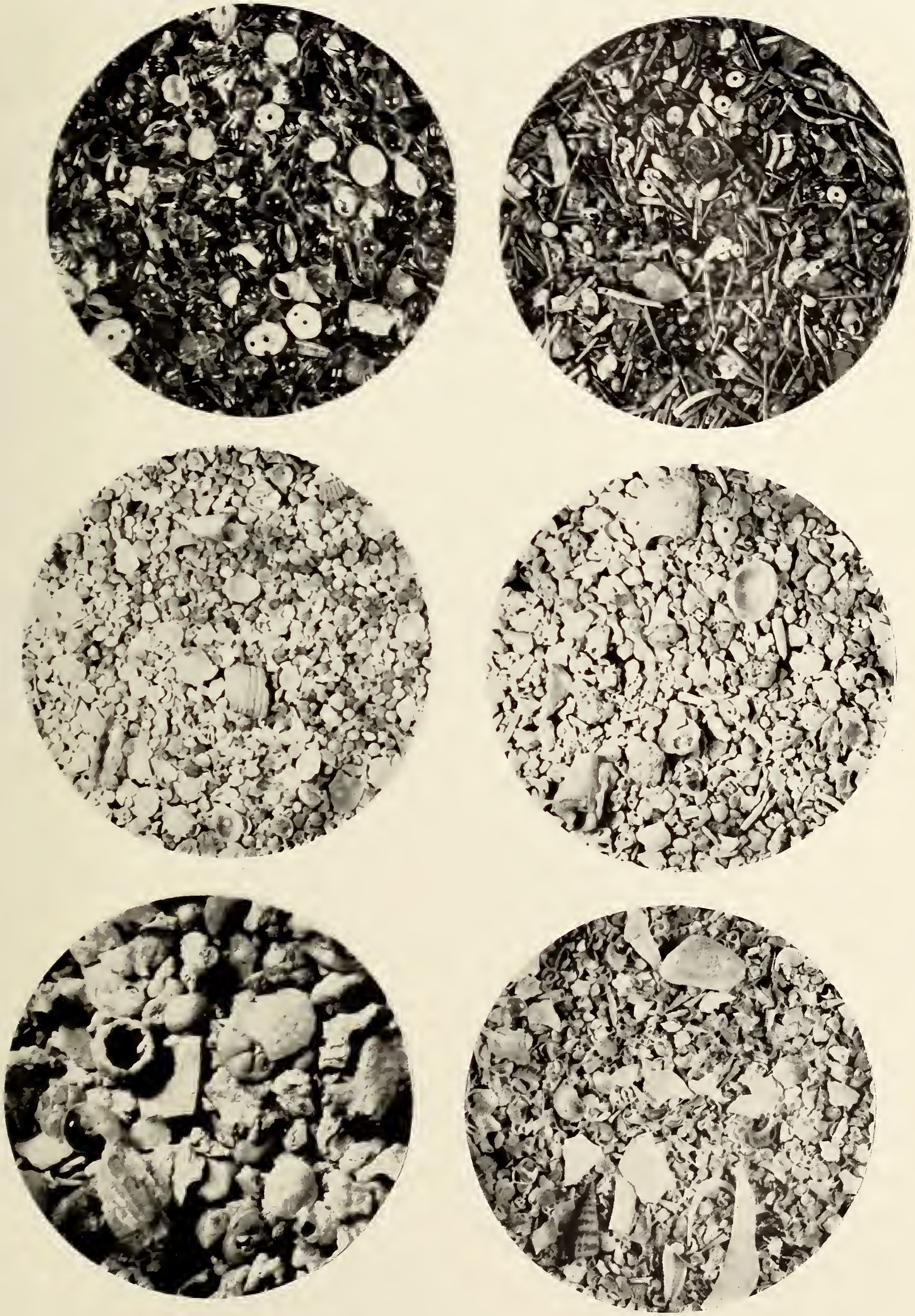
2. Pteropod Ooze, chiefly *Creseis* spp. : Sta. 75, Gulf of Oman, × 1.
    1. *Cavolinia longirostris* (Lesueur).
    2. *Diacria quadridentata* (Lesueur).
    3. *Creseis acicula* Rang.
    4. *Atlanta* sp.
    5. Lamellibranch valve.
    6. Gasteropod shells.
    7. Scaphopod shell.
    8. Echinoderm shells.
    9. Polychæt tube fragments.
    10. Crustacean fragments.

3. Coarse Coral Gravel : Sta. 139, Maldive Archipelago, × 1.
    1. Lamellibranch fragments.
    2. Gasteropod fragments.
    3. Scaphopod shell.
    4. Alcyonarian spicules.
    5. *Heterostegina* sp.
    6. *Placopsilina cenomana* d'Orbigny, on Lamellibranch shell.

4. Coarse Coral Gravel : Sta. 144, Maldive Archipelago, × 1.
    1. Lamellibranch valves.
    2. Gasteropod fragments.
    3. Echinoderm spine.
    4. Crustacean fragment.
    5. *Amphistegina radiata* (Fichtel and Moll).
    6. *Halimeda* sp.
    7. *Lithothamnion* sp.

5. Coral Sand : Sta. 163, Maldive Archipelago, × 15.
    1. *Limacina inflata* (d'Orbigny).
    2. *Atlanta* sp.
    3. Lamellibranch fragments.
    4. Gasteropod fragment.
    5. Polychæt tube fragment.
    6. Rotaliid Foraminiferan.
    7. *Amphistegina radiata* (Fichtel and Moll).
    8. *Globorotalia canariensis* (d'Orbigny).
    9. *Gl. menardii* (d'Orbigny).

6. Coral Mud : Sta. 142b, Maldive Archipelago, × 1.
    1. Lamellibranch fragments.
    2. Gasteropod shells.
    3. Echinoderm fragments.
    4. Crustacean fragments.



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DESCRIPTION OF PLATE IV.

1. *Dendrophrya ramosa* Cushman : Sta. 105, off Zanzibar, × 1.
2. *Rhabdammina abyssorum* M. Sars : Sta. 185, Gulf of Aden, × 1.

1

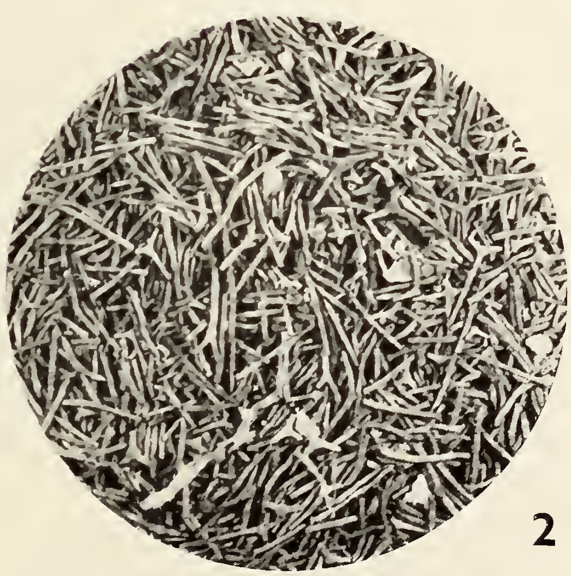

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Chart I.—Distribution of the Deposit-samples collected.

CHART II.—The Ridges and Basins of the Arabian Sea.

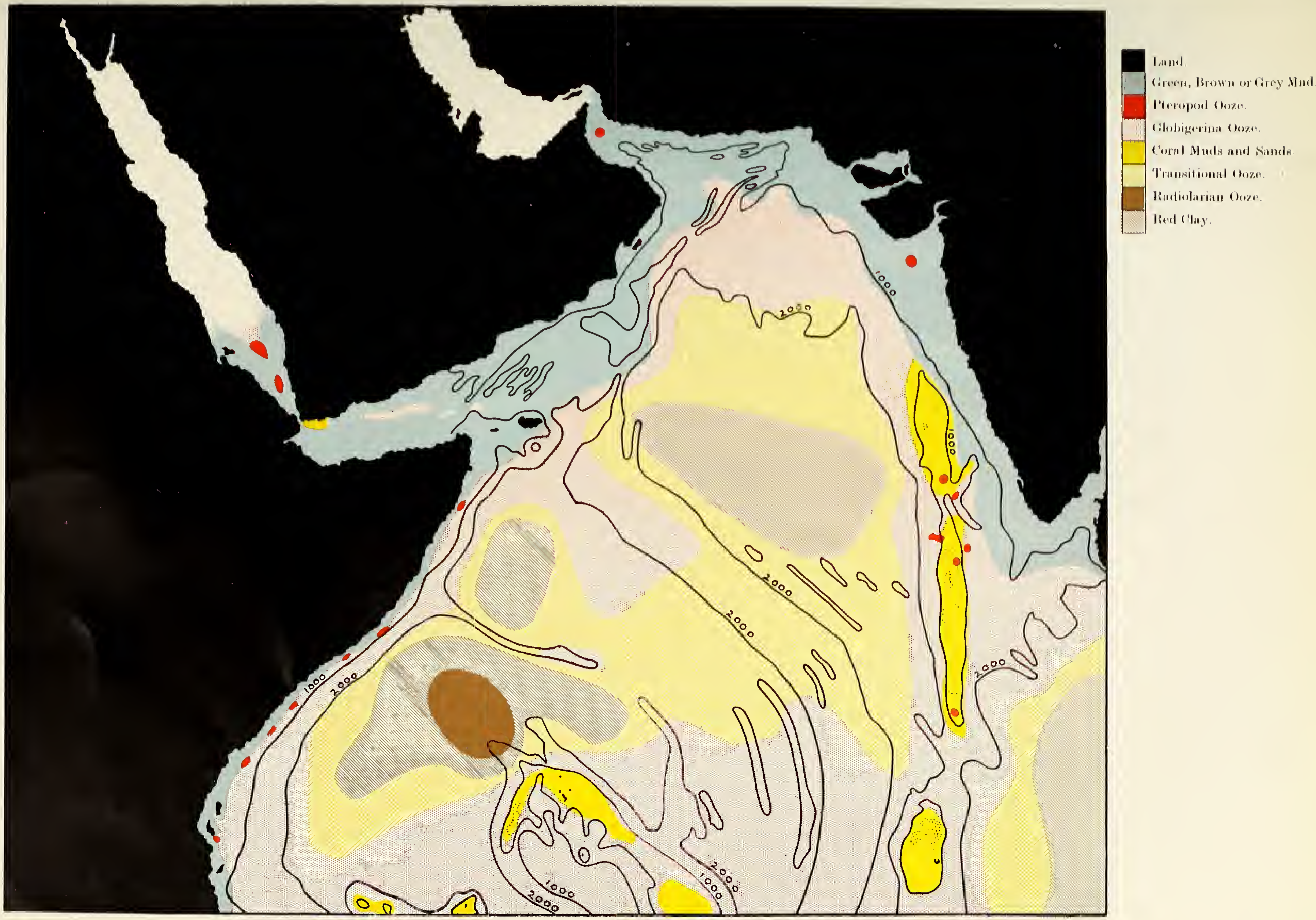

CHART III.—The Deposits of the Arabian Sea.

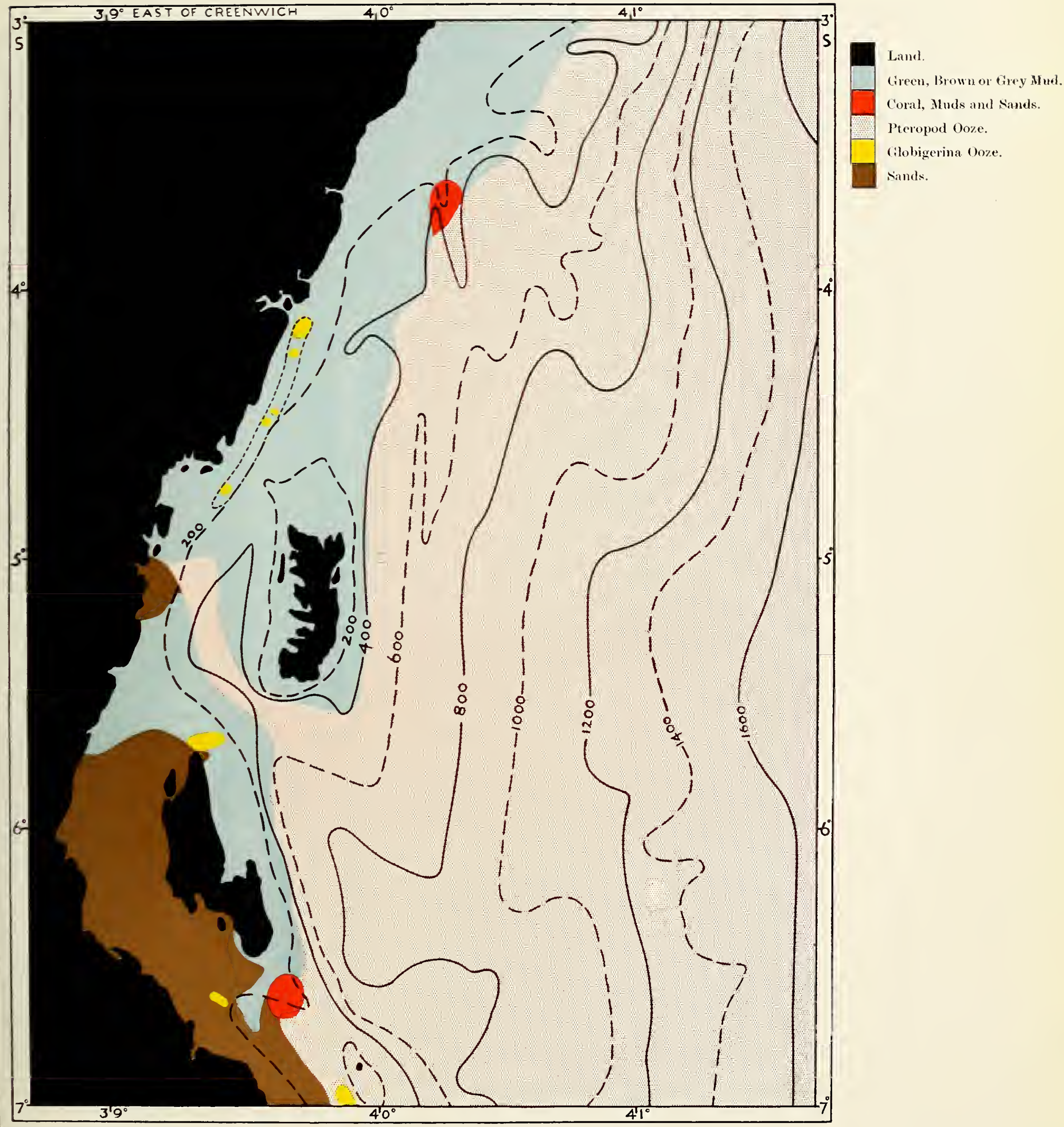

Chart IV.—The Deposits of the Zanzibar Region.

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STRATIFICATION OF BIOLOGICAL REMAINS IN MARINE DEPOSITS

BY

H. G. STUBBINGS, M.A., Ph.D.(Cantab.), B.Sc.(Lond.)

WITH FOUR TEXT-FIGURES

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I. INTRODUCTION.

Historical.

Instances of stratification of marine sediments were first recorded by Murray and Renard (1891), though without comment. Longer stratified cores have since been described and discussed by Murray and Philippi (1908), Philippi (1910), Murray (1912) and more recently by Wüst (1933), Wattenberg (1933) and Schott (1935). The materials for these investigations come largely from the Southern Ocean, and Central and Southern Atlantic. The main achievement of the work has been to date various strata in the cores as of glacial age. The essential link in the work was furnished by Wattenberg (1933), who showed that deposits formed beneath cold polar waters were poor in calcium carbonate owing to the unsaturation of polar water with this substance.

Recent work with a new type of apparatus (Piggot, 1936), driven into the deposit by an explosive charge, has resulted in the collection of cores up to 2·97 m. in length. Preliminary work on these (Bradley *et al.*, 1938) has shown that as many as four glacial strata are identifiable, inter-layered with Globigerina ooze or limy mud and with two layers of volcanic ash, one beneath the upper (surface) Globigerina ooze and the other between the third and fourth glacial strata. The different strata found are approximately as follows (Bradley *et al.*, 1938, pp. 42, 43):

1. Globigerina ooze.
2. Upper volcanic ash zone.
3. First glacial zone.
4. Globigerina ooze or limy clay.
5. Second glacial zone.
6. Globigerina ooze or limy clay.

7. Third glacial zone.
8. Lower volcanic ash zone.
9. Fourth glacial zone.
10. Globigerina ooze or limy clay.

The first two glacial zones may be only phases of one and the same glacial period, considered by Bradley *et al.* to correspond to the last or Wisconsin glaciation of North America. This large number of glacial strata has only been found west of the Mid-Atlantic Ridge. East of the Ridge only one glacial zone has so far been identified in the cores. The cores show great variation in the thickness of corresponding strata, indicating that the rate of deposition is very variable in different parts of the ocean.

Bradley *et al.* (1938) also summarise the work of Philippi (1910) and Schott (1935). That of Schott is of particular interest as it is on similar lines to the present work. Schott has shown that in Central Atlantic cores certain species of pelagic Foraminifera can be used to give indications of the temperature conditions at the time of deposition of the deposit. This leads to the possibility of dating a section of the core as of glacial age. Cold water species are found to be in the majority in glacial strata and warm-water species in the inter-glacial. Cushman (Bradley *et al.*, 1938) has found that dating of the North Atlantic cores by this means agrees with the geological interpretation.

The object of the present work is to investigate the Foraminifera of the cores obtained by the "John Murray" Expedition in an attempt to demonstrate similar "climatic" stratification of the deposits in the Arabian Sea. Only the Foraminiferal evidence is discussed here. The geological and mineralogical evidence will be discussed by co-workers on the material.

Pelagic Foraminifera.

Cushman (1933, p. 44) lists twenty-five species of wholly pelagic Foramifera and several that are pelagic for part of the life-cycle only. Schott (1935, p. 44) states that these pelagic species are for the most part stenothermic, though some are eurythermic, warm-water animals. Most species live in the warm surface waters of tropical and sub-tropical regions, where only a small annual range of temperature occurs. According to Philippi (1910, p. 568) the following species found in the Arabian Sea occur most abundantly in warm waters :

Globigerina dubia.	*Pulleniatina obliquiloculata.*
Globigerinoides conglobata.	*Sphæroidinella dehiscens.*
Gl. rubra.	*Globorotalia canariensis.*
Gl. sacculifera.	*Gl. menardii.*
Globigerinella æquilateralis.	*Gl. truncatulinoides.*
Gl. digitata.	*Gl. tumida.*
Orbulina universa.	

The following three species, among others, not recorded from the present materials, are said to be most abundant in temperate waters :

Globigerina bulloides.	*Globorotalia crassa.*
Gl. inflata.	

In the Arabian Sea the commonest species are :

Globigerina bulloides.	*Globorotalia menardii.*
Gl. dubia.	*Gl. tumida.*
Pulleniatina obliquiloculata.	

Of these, only *Globigerina bulloides* and *Globorotalia menardii* are sufficiently abundant to be of general value as indicators of changing conditions. *Globorotalia tumida* is also of considerable use, as its fluctuations agree with those of *Globorotalia menardii* ; but it is never sufficiently abundant to be used as a separate " indicator ". Other species are of occasional use where these variations are similar to those of one or other of the above species.

MATERIALS.

Six cores from Stations 119, 127, 128, 132, 134 and 135 in the Southern Arabian Sea have been examined in detail. They lie on a line from just south-east of Zanzibar to the south end of the Maldive Archipelago.

METHODS.

In all the samples examined the procedure was the same as that already used in the investigation of the surface deposits of the Arabian Sea. A small sample of the deposit was boiled in water, with the addition of potash, if necessary, until thoroughly broken down into its component particles. The material was then washed through a linen sieve which retained the Foraminifera, while allowing the fine mud to pass through the meshes.

The samples chosen for examination are from various horizons. In each core a surface sample was examined and three or four more from various parts of the core. Where possible these samples were chosen from regions of the core that appeared to differ on superficial examination. If no variations were apparent, samples were taken at levels roughly corresponding with those on other cores. Additional samples were studied as the progress of the work required. In all 43 samples were examined as shown in Table I.

TABLE I.—*Depths in cm. Below Top of Core.*

Station.

119.	127.	128.	132.	134.	135.
0	0	0	0	0	0
4·5	4·0	5·0	6·0	5·0	6·0
10·5	25·0	22·0	26·5	29·0	33·0
33·0	51·0	32·5	45·0	59·0	61·0
47·5	86·5	46·0	63·0	90·0	86·0
58·5	96·5	65·0	91·0	107·5	113·0
60·0	..	87·0	108·0	..	..
..	..	95·0	..	..	..
..	..	101·5	..	..	..
..	..	110·5	..	..	..
..	.	130·5	..	..	..

The Foraminifera are treated in some detail. The pelagic and many of the benthic species have been identified and are listed elsewhere (pp. 162, 183 *et seq.*). A sample of the washed material was spread out under the binocular and the numbers of each pelagic species counted. The benthic species, always represented by few individuals, were counted together. Sufficient material to include at least one thousand specimens was counted and the numbers of each species expressed as parts per thousand tests. The results of these counts are shown in Table II.

Table II.

Station.	Depth in core (cm.).	*Globigerina.* *bulloides.*	*Globigerina.* *dubia.*	*Globigerina.* *inflata.*	*Globigerinoides.* *conglobata.*	*Globigerinoides.* *rubra.*	*Globigerinoides.* *sacculifera.*	*Globigerinella.* *æquilateralis.*	*Globigerinella.* *digitata.*	*Orbulina universa.*	*Pulleniatina obliquiloculata.*	*Sphæroidinella dehiscens.*	*Globorotalia.* *canariensis.*	*Globorotalia.* *crassa.*	*Globorotalia.* *menardii.*	*Globorotalia.* *truncatulinoides.*	*Globorotalia.* *tumida.*	Benthic specimens.
119	0	405	117	12	30	25	32	..	..	27	94	8	..	20	125	14	42	49
	4·5	406	123	5	33	17	33	..	..	29	99	6	..	22	129	8	47	43
	10·5	638	75	6	12	16	23	..	..	13	63	3	2	15	81	11	23	19
	33·0	796	21	1	1	97	4	..	..	5	13	..	..	..	18	..	..	44
	47·5	848	21	3	2	45	6	..	..	7	18	..	..	..	25	..	1	24
	58·5	564	111	6	22	15	20	..	..	19	66	3	5	20	91	15	18	25
	65·0	512	118	7	23	14	18	..	..	24	83	3	..	17	105	15	41	21
127	0	556	66	..	65	6	47	..	..	11	57	9	..	..	126	2	42	13
	4·0	541	51	..	60	12	38	..	..	14	53	3	..	2	173	..	49	4
	25·0	343	112	2	18	6	8	..	..	20	52	6	3	24	298	1	94	13
	51·0	643	84	..	17	..	..	..	5	14	56	19	..	18	113	7	16	8
	86·5	524	71	2	15	1	1	..	..	15	71	24	..	20	206	..	40	10
	96·5	654	57	2	3	8	8	..	..	8	43	4	2	18	167	1	20	5
128	0	496	59	10	37	1	20	..	..	10	65	15	..	17	141	7	115	7
	5·0	176	56	22	20	1	7	..	..	13	145	25	..	10	331	5	181	8
	22·0	547	67	17	32	5	52	..	1	22	71	7	1	2	147	26	..	3
	32·5	450	141	1	3	2	4	..	..	5	66	5	..	52	198	7	46	20
	46·0	281	103	8	17	3	5	2	1	11	90	11	..	78	267	39	80	4
	65·0	383	97	20	14	4	20	..	..	49	74	3	5	28	275	4	20	4
	87·0	613	57	3	2	3	2	..	..	1	40	7	1	25	186	..	51	9
	95·0	302	58	6	2	1	3	..	..	8	40	8	1	12	442	6	103	8
	101·5	207	50	9	4	..	1	..	..	4	42	12	..	22	450	2	179	18
	110·5	463	18	1	4	..	1	..	..	..	56	9	..	8	300	..	125	15
	130·5	639	100	3	5	3	3	..	..	2	23	3	..	36	162	1	10	10
132	0	707	68	31	14	..	6	..	..	1	26	2	..	..	131	..	6	8
	6·0	747	45	11	12	25	34	..	2	9	30	3	1	..	71	..	4	6
	26·5	622	78	4	12	5	12	..	1	16	69	3	1	19	142	2	10	4
	45·0	476	95	18	14	..	13	..	1	48	35	3	..	45	235	2	14	1
	63·0	613	82	10	9	6	10	..	..	9	48	6	1	20	153	12	10	11
	91·0	680	47	41	8	2	6	..	2	6	36	7	2	20	130	6	4	3
	108·0	728	49	28	9	1	11	1	2	10	40	3	1	12	96	2	3	4
134	0	479	36	2	..	..	..	..	..	3	27	46	..	..	318	..	16	73
	5·0	510	41	5	1	..	2	..	..	..	16	12	..	12	354	..	29	18
	29·0	378	46	52	12	2	2	..	..	6	68	24	..	24	350	..	24	12
	59·5	464	34	18	..	1	..	..	..	4	49	31	..	5	289	..	61	44
	90·0	288	130	82	8	..	17	21	..	16	29	37	..	..	243	..	64	65
	107·5	312	83	118	10	..	16	12	..	18	81	16	..	..	254	..	21	59
135	0	575	59	32	9	117	32	9	4	15	46	2	..	..	71	..	3	26
	6·0	528	97	43	13	39	39	14	13	22	70	2	14	..	98	..	3	5
	33·0	570	90	27	14	68	42	3	22	31	52	1	3	4	66	1	2	4
	61·0	446	115	38	10	119	22	30	..	25	49	..	..	..	121	..	4	21
	86·0	492	81	48	13	42	24	30	14	28	73	4	17	8	139	1	8	5
	113·0	372	113	58	13	67	19	47	4	17	108	3	..	..	153	..	4	22

II. DESCRIPTION OF THE CORES EXAMINED.

In this section the origin and appearance of the cores are briefly described and the main variations in Foraminiferal content are outlined. Details of the behaviour of individual species are given in a later section (p. 168 *et seq.*) under each species.

Station 119.

Locality : South-east of Zanzibar.

Depth : 1204 m.

Length of Core : 68·5 cm.

Description : The upper 9·0 cm. is a typical pale brown Globigerina ooze. Below this, from 9·0–60·0 cm., lies a layer of very coherent mud containing far fewer specimens of pelagic Foraminifera. From 60·0 cm. to the bottom, the core is composed of Globigerina ooze very similar to that at the top of the core.

The change in Foraminiferal content in the central portion is at once seen by reference to Table II, Sta. 119 : the depths 10·5, 33·0 and 47·5 cm. lie in this layer. The corresponding figures show the numbers of each species in this zone as compared with the Globigerina ooze above and below. The numbers at 10·5 and 58·5 cm. are those in the transition layers between the mud and the Globigerina ooze. It is seen that the relative numbers of *Globigerina bulloides*, and to a lesser extent of *Globigerinoides rubra*, have increased at the expense of the other species enumerated.

The number of benthic specimens is much lower in the bottom part of the core.

There is no significant difference between the numbers of most of the pelagic species found at the surface of the deposit and at the deepest level examined—65·0 cm. It is reasonable, therefore, to assume that the Globigerina oozes at the top and bottom of this core are very similar in composition ; from which it follows that environmental conditions at the times when the top and bottom materials were deposited were similar. The probable times of deposition of these zones will be referred to later.

The following table shows those species that are more abundant and those that are rarer at 47·5 cm. (the level where *Globigerina bulloides* is most abundant) as compared with the level below.

More abundant species.	Less abundant species.
Globigerina bulloides.	*Globigerina dubia.*
Globigerinoides rubra.	*Gl. inflata.*
	Globigerinoides conglobata.
	Gl. sacculifera.
	Orbulina universa.
	Pulleniatina obliquiloculata.
	Sphæroidinella dehiscens.
	Globorotalia crassa.
	Gl. menardii.
	Gl. truncatulinoides.
	Gl. tumida.

The majority of the less abundant species are warm-water forms. *Globigerina inflata* and *Globorotalia crassa*, however, are cold-water species. *Globigerinoides rubra* is also a warm-water species, but is commoner in this zone.

Station 127.

Locality : South Somali Basin.

Depth : 4091 m.

Length of core : 96·5 cm.

Description : The core consists throughout of a brownish Globigerina ooze. There is no visible difference in the texture of the deposit at any horizon. At 57·5 cm. there is a slight change in colour to a greyish brown.

There is a significant drop in the numbers of *Globigerina bulloides* at 25·0 cm. (Table II), with a corresponding rise in numbers of the warm-water forms *Globorotalia menardii* and *Gl. tumida.* Somewhat lower, at 51·0 cm., there is a big rise in the numbers of *Globigerina bulloides,* probably to be correlated with the colour change at 57·5 cm., with a considerable fall in numbers of both *Globorotalia menardii* and *Gl. tumida.* Lower still, at 86·5 cm., the number of *Globigerina bulloides* is very near that in the two top samples. The numbers of *Globorotalia tumida* also are approximately equal at the surface and in this sample. At 96·5 cm. the number of *Globigerina bulloides* is still higher and many of the other species are less abundant than at 86·5 cm.

The following species show significant differences in abundance at the depths indicated as compared with the numbers in the sample next below :

	More abundant species.	Less abundant species.
4·0 cm.	*Globigerina bulloides.*	*Globigerina dubia.*
	Globigerinoides conglobata.	*Orbulina universa.*
	Gl. rubra.	*Sphæroidinella dehiscens.*
	Gl. sacculifera.	*Globorotalia crassa.*
		Gl. menardii.
		Gl. tumida.

Thus the commonest cold-water species, *Globigerina bulloides,* shows an increase, while *Globorotalia crassa,* also a cold-water form, shows a decrease in numbers. Similarly, while most warm-water species show a decrease in numbers, the three species of *Globigerinoides* show an increase.

25·0 cm.	*Globigerina dubia.*	*Globigerina bulloides.*
	Globigerinoides rubra.	*Sphæroidinella dehiscens.*
	Gl. sacculifera.	
	Orbulina universa	
	Globorotalia crassa.	
	Gl. menardii.	
	Gl. tumida.	

Several other species show slight changes in numbers at this level. Of the above, more abundant species, only one, *Globorotalia crassa,* is a cold-water form.

51·0 cm.	*Globigerina bulloides.*	*Pulleniatina obliquiloculata.*
	Gl. dubia.	*Sphæroidinella dehiscens.*
		Globorotalia menardii.
		Gl. tumida.

In addition, *Globigerinoides conglobata* shows a slight increase and *Globorotalia crassa* a slight decrease in numbers.

86·5 cm.	*Globigerina dubia.*	*Globigerina bulloides.*
	Globigerinoides conglobata.	*Globigerinoides rubra*
	Orbulina universa.	*Gl. sacculifera.*
	Pulleniatina obliquiloculata.	
	Sphæroidinella dehiscens.	
	Globorotalia menardii.	
	Gl. tumida.	

Thus several species said to be warm-water forms fluctuate with *Globigerina bulloides* at this station, while *Globorotalia crassa*, a cold-water form, agrees with the warm-water species in the top 4·0 cm. of the core.

There is thus an alternate rise and fall in the numbers of most species at this station. Furthermore, the species with some exceptions fall into two groups. One group shows an increase in numbers while the other shows a decrease at the same horizon. At alternate horizons the other group shows an increase.

The species thus show three fluctuations as against the one in the core from Sta. 119. Similar fluctuations, though not always three in number, occur in all the following cores.

Station 128.

Locality : South Somali Basin.

Depth : 4060 m.

Length of core : 132·0 cm.

Description : A transitional ooze throughout, similar to that from Sta. 127 but containing more red clay.

Large numbers of *Globigerina bulloides* occur at 0, 22·0, 87·0 and 130·5 cm. Small numbers of *Pulleniatina obliquiloculata*, *Globorotalia menardii* and *Gl. tumida* correspond to each of these. The commoner species exhibit four maxima (*Gl. bulloides*) or minima (*Globorotalia menardii*).

The following species are more or less abundant at the levels where *Globigerina bulloides* is present in large numbers, as compared with the sample next below :

	More abundant species.	Less abundant species.
0 cm.	*Globigerina bulloides.*	*Globigerina inflata.*
	Gl. dubia.	*Orbulina universa.*
	Globigerinoides conglobata.	*Pulleniatina obliquiloculata.*
	Gl. sacculifera.	*Sphæroidinella dehiscens.*
	Globorotalia crassa.	*Globorotalia menardii.*
	Gl. truncatulinoides.	*Gl. tumida.*
22·0 cm.	*Globigerina bulloides.*	*Globigerina dubia.*
	Gl. inflata.	*Globorotalia crassa.*
	Globigerinoides conglobata.	*Gl. menardii.*
	Gl. rubra.	*Gl. tumida.*
	Gl. sacculifera.	
	Orbulina universa.	
	Pulleniatina obliquiloculata.	
	Sphæroidinella dehiscens.	
	Globorotalia truncatulinoides.	

	More abundant species.	Less abundant species.
87·0 cm.	*Globigerina bulloides.*	*Globigerina inflata.*
	Globigerinoides rubra.	*Globigerinoides conglobata.*
	Globorotalia crassa.	*Gl. sacculifera.*
		Orbulina universa.
		Sphæroidinella dehiscens.
		Globorotalia menardii
		Gl. truncatulinoides.
		Gl. tumida.
130·5 cm.	*Globigerina bulloides.*	*Pulleniatina obliquiloculata.*
	Gl. dubia.	*Sphæroidinella dehiscens.*
	Gl. inflata.	*Globorotalia menardii.*
	Globigerinoides conglobata.	*Gl. tumida.*
	Gl. rubra.	
	Gl. sacculifera.	
	Globorotalia crassa.	

Comparing these four levels, it is seen that certain species fluctuate in the same direction fairly constantly. Thus *Globigerina bulloides, Gl. dubia, Globigerinoides conglobata, Gl. sacculifera* and *Globorotalia crassa* tend to increase together. At the same levels *Globigerina inflata, Orbulina universa, Pulleniatina obliquiloculata, Sphæroidinella dehiscens, Globorotalia menardii* and *Gl. tumida* usually fall in numbers. At 22·0 cm. *O. universa, P. obliquiloculata* and *Sph. dehiscens* actually increase, but in the case of the latter two the increase is very small. The remaining species, the numbers of which are often small, do not follow either of the species, *Globigerina bulloides* and *Globorotalia menardii.*

In the intervening samples from this core the set of species containing *Gl. menardii* increases, while the numbers of the other set decrease.

Station 132.

Locality : On the Carlsberg Ridge.

Depth : 4082 m.

Length of core : 116·0 cm.

Description : An almost pure, pale cream Globigerina ooze. The portion from 70·0 cm. to the bottom is greyish in colour.

There is a very distinct maximum concentration of *Globigerina bulloides* at 6·0 cm. (Table II) and again at 108·0 cm., in both cases coincident with low numbers of *Globorotalia menardii. Globigerina bulloides* is least common at 45·0 cm. where *Globorotalia menardii* exhibits a maximum. The species showing an increase or decrease in numbers at 6·0 cm. and 45·0 cm. are shown below. Most of those showing a decrease at 6·0 cm. show an increase at 45·0 cm.

	More abundant species.	Less abundant species.
6·0 cm.	*Globigerina bulloides.*	*Globigerina dubia.*
	Gl. inflata.	*Orbulina universa.*
	Globigerinoides rubra.	*Pulleniatina obliquiloculata.*
	Gl. sacculifera.	*Globorotalia crassa.*
		Gl. menardii.
		Gl. tumida.
		Gl. truncatulinoides.

	More abundant species.	Less abundant species.
45·0 cm.	*Globigerina dubia.*	*Globigerina bulloides.*
	Gl. inflata.	*Globigerinoides rubra.*
	Globigerinoides conglobata.	*Pulleniatina obliquiloculata.*
	Gl. sacculifera.	*Sphæroidinella dehiscens.*
	Orbulina universa.	*Globorotalia truncatulinoides.*
	Globorotalia menardii.	
	Gl. crassa	
	Gl. tumida.	

Station 134.

Locality : South end of the Arabian Basin, west of the Maldive Archipelago.

Depth : 4234 m.

Length of core : 118·0 cm.

Description : Globigerina ooze throughout.

There are slightly larger numbers of *Globigerina bulloides* in this core at 5·0 cm., corresponding to the maximum of this species at 6·0 cm. in the preceeding core This increase is not, however, reflected by a low concentration of *Globorotalia menardii*, which is most abundant at this level. *Pulleniatina obliquiloculata* is rather scarce here. Small numbers of *Gl. bulloides* were found at 90·0 cm., corresponding to slightly increased numbers of *Globorotalia tumida*, but not of *Gl. menardii*. Both *Globigerina bulloides* and *Globorotalia menardii* are more abundant again at 107·5 cm., but *Gl. tumida* is less frequent.

It is remarkable that at this station *Globigerina bulloides* and *Globorotalia menardii* increase at the same horizons, whereas at the other stations they almost always fluctuate in opposite directions. The fluctuations of other species are also irregular.

Station 135.

Locality : West of the Maldives, on the edge of the Arabian Basin.

Depth : 2727 m.

Length of core : 120·5 cm.

Description : Globigerina ooze throughout. The upper 28·5 cm. are fawn-coloured. Below this level the deposit has a greyish tint, which is more pronounced from 86·0 cm. to the bottom of the core.

Large numbers of *Globigerina bulloides* occur at 0 and 33·0 cm. along with small numbers of other species (see Table II). Below the latter level the numbers of *Globigerina bulloides* decrease fairly steadily, while those of *Pulleniatina obliquiloculata* and *Globorotalia menardii* increase. The species differing in abundance at 0 and 33·0 cm. are shown below.

	More abundant species.	Less abundant species.
0 cm.	*Globigerina bulloides.*	*Globigerina dubia.*
	Globigerinoides rubra.	*Gl. inflata.*
		Globigerinoides conglobata.
		Gl. sacculifera.
		Orbulina universa.
		Pulleniatina obliquiloculata.
		Globorotalia menardii.

	More abundant species.	Less abundant species.
33·0 cm.	*Globigerina bulloides.*	*Globigerina dubia.*
	Globigerina conglobata.	*Gl. inflata.*
	Gl. sacculifera.	*Globigerinoides rubra.*
	Orbulina universa.	*Globorotalia menardii.*
	Pulleniatina obliquiloculata.	*Gl. tumida.*

In the above lists the less common species have been omitted.

Orbulina universa and *Pulleniatina obliquiloculata* behave irregularly at this station. At the surface they agree with the warm-water species, *Globorotalia menardii*, in being less common, but at 33·0 cm. they are present in increased numbers, though here the warm-water species are again less common.

As already remarked (p. 165), it is apparent from the foregoing lists that a number of species tend usually to fluctuate in the same direction. Thus the following six species frequently show an increase or decrease in numbers at the same level :

Globigerina inflata. *Sphæroidinella dehiscens.*
Orbulina universa. *Globorotalia menardii.*
Pulleniatina obliquiloculata. *Gl. tumida.*

Of this group, *Gl. menardii* is the most abundant.

Globigerina bulloides almost always shows an opposite fluctuation to the above species. No other species varies in this manner so constantly, but the following frequently fluctuate with *Gl. bulloides*, though occasionally they may agree with the above group of species :

Globigerina dubia. *Globigerinoides sacculifera.*
Globigerinoides conglobata. *Globorotalia crassa.*
Gl. rubra.

The remaining four species, *Globigerinella æquilateralis*, *Gl. digitata*, *Globorotalia canariensis* and *Gl. truncatulinoides*, are rarer or do not show any marked tendency to agree with either *Globigerina bulloides* or *Globorotalia menardii.*

III. THE PELAGIC FORAMINIFERA.

The same pelagic species occur constantly in almost all the samples examined from the six cores. The sixteen species represented will be treated individually below, and an account of the fluctuations, which I have briefly outlined in the previous section, will be amplified under each species.

Globigerina bulloides d'Orbigny.

This is a cold-water species. Tests are always present and for the most part fragmentary. The following figures show the number likely to be present in a 1000 tests of all kinds from the deposit :

Range of numbers 176–848 per 1000.[1]

Mean 530.

Distribution : There appears to be no correlation of this species with depth or distance

[1] The " range of numbers " gives the largest and smallest numbers of the species found in all the samples from all the cores. The " mean " is the average of all these samples.

from land. It appears to be fairly evenly distributed over the whole Arabian Sea in the deposits. The following means were found for the six stations :—

Station	119	127	128	132	134	135
Mean	596	544	414	653	405	497[1]

Reference to Table II shows that the number of examples of this species that are present frequently shows violent fluctuations. The fluctuations at each station are as follows :

Sta. 119 : The two top samples and the lowest contain similar numbers. (This is also the case for other species in this core.) The intermediate portion contains many more *Globigerina bulloides*. This is the mud portion of the core ; the other samples are from Globigerina ooze.

Sta. 127 : There are very large numbers of *Globigerina bulloides* at about 51·0. cm. ; a little higher up at 25·0 cm. the number is almost halved. Higher still, in the top two samples, the number is high again and approximates to that found at 86·5 cm. At 96·5 cm. the number of *Gl. bulloides* is higher than at 51·0 cm. The surface maximum apparently corresponds to that at Sta. 119. The other two maxima are not represented at that station.

Sta. 128 : As already mentioned, the number of specimens fluctuates considerably from level to level. Large numbers occur at 0, 22·0, 87·0 and 130·5 cm. There is a very big drop in numbers at 5·0 cm. and smaller ones between the above levels.

Sta. 132 : There is a steady fall to the middle of this core and then a rise to the bottom. Large numbers occur at 6·0 and 108·0 cm.

Sta. 134 : Fluctuations are small at this station. Large numbers occur at 5·0 cm. and there are other slight increases in numbers at 59·5 and 107·5 cm. Smaller numbers occur in the intermediate levels, especially at 90·0 cm.

Sta. 135 : Large numbers occur at 0 and 33·0 cm. with a small drop in between at 6·0 cm. Numbers are considerably less in the lower levels, with a decided minimum at 113·0 cm.

Globigerina dubia Egger.

This species inhabits warmer waters than the preceding, and is probably most abundant in temperate-subtropical regions. It is fairly common in all samples examined. The tests are usually intact. The following are the numbers of specimens found :

Range of numbers 21–141 per 1000.
Mean 75.

Distribution : There appears to be some correlation between the number of tests present and the depth. The species is also rather more abundant in deposits from the western side of the Arabian Sea, though it occurs commonly throughout the area. The figures below illustrate this correlation (the stations are in order from west to east) :

Station	119	127	128	132	134	135
Mean	84	74	73	66	62	93
Depth (m.)	1204	4091	4060	4082	4234	2727

Sta. 119 : The numbers at the top and bottom of the core are similar, as in the case of

[1] These means are an average of the samples from all the levels at the respective stations.

the preceding species. Very few in comparison occur in the levels (33·0 and 47·5 cm.) in which *Globigerina bulloides* is so abundant. The same phenomenon is seen in all the following species, with the exception of *Globigerinoides rubra*, and need not be reiterated under each one.

Sta. 127 : The maximum number occurs with the minimum of *Globigerina bulloides* at 25·0 cm. At other levels above and below this horizon the numbers are considerably less.

Sta. 128 : The maximum number of tests is found just below the level of the second *Globigerina bulloides* maximum (22·0 cm.) at 32·5 cm. A second large number occurs with many *Gl. bulloides* at 130·5 cm., but the intermediate *Gl. bulloides* maximum at 87·0 cm. is not represented.

Sta. 132 : Low numbers correspond to the upper *Gl. bulloides* maximum. There is a maximum concentration at 45·0 cm. Below this level the number of specimens falls off.

Sta. 134 : Numbers are relatively uniform in the upper half of the core. There is a very definite maximum at 90·0 cm. where *Globigerina bulloides* is less frequent.

Sta. 135 : The species varies inversely as *Globigerina bulloides* at all horizons.

Thus *Globigerina dubia* appears as a rule to vary inversely as *Gl. bulloides*, but it appears to fluctuate irregularly at Sta. 128. This inconsistency renders it unreliable as a guide to climatic conditions.

Globigerina inflata d'Orbigny.

Globigerina inflata is a cold-water form. It is present at all six stations in small numbers, but is absent from three of the horizons examined at Sta. 127. The tests are usually intact.

Range of numbers 0–118 per 1000.
Mean 19.

The numbers of this species are very much higher at the three eastern stations. There is no apparent depth correlation. Mean numbers for each station follow :

Station	119	127	128	132	134	135
Mean	6	1	9	21	46	41

Sta. 119 : Although this is a cold-water form there is no maximum at this station corresponding to that of *Globigerina bulloides*. On the contrary, only one test in a thousand at this horizon belongs to this species. A possible explanation of this apparent anomaly may be that both species occupy the same habitat, and are in competition and the more abundant *Globigerina bulloides* ousts the other.

Sta. 127 : The species is very rare.

Sta. 128 : The numbers fluctuate in the opposite direction to those of *Globigerina bulloides*, except between 22·0 and 32·5 cm., where both decrease in numbers. There are considerably more specimens in the upper 22·0 cm. than at any lower level except at 65·0 cm.

Sta. 132 : Increased numbers lie at different levels to those of *Globigerina bulloides*. There is a distinct minimum at 26·5 cm., above that of the latter species. The numbers rise at 45·0 cm., where *Globigerina bulloides* is scarcest, fall somewhat at 63·0 cm., and rise again at 91·0 cm. to fall again at 108·0 cm., where *Gl. bulloides* increases in numbers again.

Sta. 134 : The upper 5·0 cm. are poor in *Globigerina inflata*. Greater numbers occur at 29·0 and 90·0 cm. At 107·5 cm. there is a further increase in numbers, though *Globigerina bulloides* also increases at this level.

Sta. 135 : *Globigerina inflata* is quite common at all levels in this core. Fluctuations alternate with those of *Gl. bulloides* down to 61·0 cm. At 86·0 cm. this species and *Gl. bulloides* are both more common than at the level above (61·0 cm.), but at 113·0 cm. *Gl. bulloides* decreases in numbers, while *Gl. inflata* rises to its maximum.

Globigerinoides conglobata (Brady).

This species is present in all but two of the samples examined. It is never very common, though quite frequent at Sta. 127. According to Philippi (1910, p. 568) it is a warm-water species.

Range of numbers 0–65 per 1000.
Mean 15.

Gl. conglobata appears to be rather commoner on the west side of the Arabian Sea. The following are average numbers per sample at each station :

Station	119	127	128	132	134	135
Mean	18	27	13	11	5	12

Sta. 119 : In the mud zone (33·0–47·5 cm.) this species is extremely rare, but it is fairly common in the two Globigerina ooze zones (0–10·5 cm. and 58·5–65·0 cm.). Rather fewer specimens occur in the lower Globigerina ooze as compared with the upper.

Sta. 127 : The number of specimens in the upper 4·5 cm. is considerably higher than elsewhere in the core. It falls steadily from the top to near the bottom of the core and then sharply at the bottom. There is no fluctuation in numbers corresponding to the increase in numbers of *Globigerina bulloides* at 51·0 cm.

Sta. 128 : Numbers are high in the upper 22·0 cm. There is a marked fall at 32·5 cm. followed by a rise at 46·0 cm. and a second fall at 87·0 cm. From this point to the bottom of the core *Gl. conglobata* is uncommon. These variations correspond to opposite fluctuations of *Globigerina bulloides*.

Sta. 132 : There is little change in numbers in the top 45·0 cm. At 63·0 cm. the number falls slightly and remains constant from this level to the bottom of the core.

Sta. 134 : *Globigerinoides conglobata* is absent from two horizons. Those in which it is fairly common (29·0 and 107·5 cm.) are those in which *Globigerina bulloides* is less common.

Sta. 135 : The species is uniformly abundant throughout the core.

Globigerinoides rubra (d'Orbigny).

This species is present at all stations though absent from some samples. It is generally rare, but rather common at all levels at Sta. 135. It is said to occur mainly in warm waters.

Range of numbers 0–119 per 1000.
Mean 18.

The tests of this species seem to survive best in shallow water. Being very small, they are presumably easily broken and dissolved. The means at each station follows :

Station	119	127	128	132	134	135
Mean	33	6	2	6	1	75

Sta. 119 : It is fairly common throughout the core, especially at 33·0 cm. Of all the pelagic species this and *Globigerina bulloides* are the only ones to be more abundant at this level than elsewhere.

Sta. 127 : It is present in the upper half of the core, but practically absent below. A maximum occurs at 4·0 cm., but there is no apparent correlation with the fluctuations of *Globigerina bulloides.*

Sta. 128 : A few specimens occur at each level except 101·5 and 110·5 cm.

Sta. 132 : There is a maximum at 6·0 cm. corresponding to one of *Globigerina bulloides.* Below this level few specimens occur.

Sta. 134 : The species is almost absent.

Sta. 135 : There is a maximum at the surface (cf. *Globigerina bulloides*), and another at 61·0 cm., somewhat lower than that of *Gl. bulloides.* There is a considerable drop in numbers at 86·0 cm. and a slight rise at 113·0 cm.

Globigerinoides sacculifera (Brady).

This warm-water species is present in most of the samples examined. The range in number of specimens is smaller than for *Globigerinoides rubra.*

Range of numbers 0–52 per 1000.
Mean 15.

It appears to be fairly evenly distributed in the deposits, with a slight tendency to be commoner in the lesser depths.

Station	119	127	128	132	134	135
Mean	19	17	11	13	6	30

Sta. 119 : This species shows the fall in numbers at 33·0 cm. already seen in the foregoing species with the exception of *Globigerinoides rubra.* The number increases again in the lower layer of Globigerina ooze, but is slightly less than in the upper layer.

Sta. 127 : Considerable numbers occur in the upper 4·0 cm., but there is a big drop at a depth of 25·0 cm. Lower in the core the species is practically absent, but it is a little more frequent at the very bottom of the core.

Sta. 128 : *Gl. sacculifera* is fairly common at the surface, but in the first 5·0 cm. the number drops to a third of its surface value. At 22·0 cm. it rises considerably to fall again at 32·5 cm., and to rise again at 65·0 cm. The species is rare from 87·0 cm. to the bottom of the core.

Sta. 132 : The maximum number is found at 6·0 cm. This is in agreement with *Globigerina bulloides* and *Globigerinoides rubra* at this station. At 26·5 cm. and lower the number is much less and reaches a minimum at 91·0 cm., equal to the number at the surface.

Sta. 134 : The distribution is the reverse of that at Sta. 127. There are very few specimens in the first 60·0 cm., but from 90·0 cm. to the bottom the number is greater.

Sta. 135 : *Globigerinoides sacculifera* is common here. The largest numbers occur at 33·0 cm. Below this level the numbers are only about half those in the upper half of the core. In this half slightly more specimens occur at 86·0 cm. There is a further slight fall in numbers at 113·0 cm. at the bottom of the core.

Globigerinella æquilateralis (Brady).

This is a warm-water species. It is very rare, but occurs rather commonly at Sta. 135.

Range of numbers 0–47 per 1000.
Mean 4.

Like *Globigerina inflata* it occurs chiefly in the eastern Arabian Sea. The following are the mean numbers per station:

Station	119	127	128	132	134	135
Mean	0	0	0	0	6	22

The species was not found at Stas. 119 and 127, and is practically absent from Stas. 128, and 132.

Sta. 134 : It occurs in fair numbers from 90·0 cm. to the bottom of the core, but is absent above this level.

Sta. 135 : Two maxima occur, at 6·0 and 113·0 cm. These correspond to small numbers of *Globigerina bulloides*. Very few tests occur at 33·0 cm. The species is much more abundant in the lower half of the core.

Globigerinella digitata (Brady).

This species also occurs mainly in tropical waters. It is rare in the Arabian Sea.

Range of numbers 0–22 per 1000.
Mean 2.

The species was not found at Stas. 119 and 134, and is rare at Stas. 127 and 128. It is slightly commoner at Sta. 132.

Sta. 135 : The species is fairly common here. The highest numbers occur at 33·0 cm. It was not found at 61·0 cm.

Orbulina universa d'Orbigny.

Although widely distributed the species is most abundant in tropical waters. Fragments of the test of this species are recognizable in all but one sample from Sta. 134 ; whole tests are often wanting. It is most abundant at Sta. 135.

Range of numbers 0–49 per 1000.
Mean 14.

O. universa seems to be generally distributed over the Arabian Sea, occurring rather more frequently in shallow water (Stas. 119, 135). Mean numbers per station follow :

Station	119	127	128	132	134	135
Mean	18	14	11	14	7	23

Sta. 119 : There is a sharp fall in numbers at 33·0 cm., in the mud section of this core. The numbers rise again in the lower layer of Globigerina ooze.

Sta. 127 : A single maximum occurs at 25·0 cm. corresponding to a decrease in *Globigerina bulloides*. The numbers at all levels tend to vary inversely with those of *Globigerina bulloides*.

Sta. 128 : The species is more abundant in the upper half of the core. Increased numbers occur at 22·0 and 65·0 cm.

Sta. 132 : Greatly increased numbers occur at 45·0 cm. There is a slight rise at 108·0 cm.

Sta. 134 : The species is rare in the upper 60·0 cm. of the core. Considerably more specimens occur in the lower half, being most abundant from about 90·0 cm. to the bottom of the core.

Sta. 135 : Maximum numbers occur at 33·0 and 86·0 cm. corresponding to high numbers of *Globigerina bulloides.*

Pulleniatina obliquiloculata (Parker and Jones).

This warm-water species is frequently abundant ; it is present in all the samples examined.

Range of numbers 13–145 per 1000.
Mean 56.

The tests are very common at all stations, as the following means show :

Station	119	127	128	132	134	135
Mean	62	55	65	41	48	66

Sta. 119 : The species is very common except in the mud section, *i.e.*, at 33·0 and 47·5 cm. It is most abundant in the upper Globigerina ooze layer.

Sta. 127 : Numbers are rather constant throughout most of the core, but rise to a maximum at 86·5 cm.

Sta. 128 : Larger numbers are found at 5·0, 46·0 and 110·5 cm., at all of which levels *Globigerina bulloides* is rather less common than at adjacent levels. Comparatively few specimens occur at 130·5 cm. Apart from the increased numbers at 46·0 and 110·5 cm., there is a fairly steady decrease in numbers from 5·0 cm. to the bottom of the core.

Sta. 132 : The species is most common in the centre of the core between 26·5 and 63·0 cm.

Sta. 134 : Larger numbers occur at 29·0 and 107·5 cm. The first of these corresponds to low numbers of *Globigerina bulloides.* The second is 17·5 cm. lower than the second *Gl. bulloides* minimum. Small numbers correspond to the *Gl. bulloides* maximum at 5·0 cm.

Sta. 135 : The fluctuation in numbers is opposite to that of *Globigerina bulloides,* but there is no rise corresponding to the fall in numbers of this species at 61·0 cm.

Sphæroidinella dehiscens (Parker and Jones).

Whole tests are uncommon, but fragments occur in most of the samples examined. It is most common at Sta. 134.

Range of numbers 0–46 per 1000.
Mean 9.

The species tends to be more frequent in deep-water samples. This is doubtless due to the greater resistance of the massive test of this species to solution compared with more delicate forms. The following are the average numbers at each station :

Station	119	127	128	132	134	135
Depth (m.)	1204	4091	4060	4082	4234	2727
Mean	3	11	10	5	28	2

It is thus commonest in the core from the deepest locality.

Sta. 119 : Only a few specimens occur here, none of them in the mud section of the core.

Sta. 127 : Few specimens occur in the upper part of the core. The species is quite frequent at 51·0 and 86·5 cm. The highest numbers occur at the latter depth.

Sta. 128 : The distribution is the reverse of that at the previous station. Most specimens occur in the top 5·0 cm. The number of specimens varies inversely with the number of *Globigerina bulloides*. There is a sharp drop in numbers at 65·0 and 130·5 cm.

Sta. 132 : The species is rather uncommon. Slight increases in the numbers present occur at 63·0 and 91·0 cm.

Sta. 134 : Maximum numbers occur at the surface and at 90·0 cm., but there is no increase or decrease comparable to the drop in numbers of *Globigerina bulloides* at 29·0 cm.

Sta. 135 : The species is rare and is quite absent at 61·0 cms.

Globorotalia canariensis (d'Orbigny).

This species was only found in a few samples. It is fairly common at two levels from Sta. 135, but elsewhere it is rare.

Range of number 0–17 per 1000.
Mean 1.

The average number per 1000 at each station is less than 1 except at Sta. 135, where the mean rises to 6, due to much larger numbers of specimens at 6·0 and 86·0 cm.

Globorotalia crassa (d'Orbigny).

This species occurred in about three-fourths of the samples, and is most frequent at Sta. 128. It is one of the few cold-water forms present in the deposits.

Range of numbers 0–78 per 1000.
Mean 15.

Gl. crassa appears to be commoner in deposits west of the Carlsberg Ridge, as the following figures indicate (Sta. 132 is on the Ridge) :

Station	119	127	128	132	134	135
Mean	13	14	26	17	7	2

Sta. 119 : This species is entirely absent at 33·0–47·5 cm. At higher and lower horizons the numbers are approximately equal.

Sta. 127 : A distinct maximum concentration of the species occurs at 25·0 cm., where fewer *Globigerina bulloides* occur. It is very rare in the top 4·0 cm. of this core.

Sta. 128 : The largest numbers occur at 46·0 and 130·5 cm., and there are marked minima at 22·0 and 110·0 cm. The maximum at 46·0 cm. coincides with the middle *Globigerina bulloides* minimum.

Sta. 132 : The species is absent in the top 6·0 cm., where *Globigerina bulloides* is abundant. In the middle of the core it is fairly common, especially at 45·0 cm., where *Gl. bulloides* is at its minimum, and at the bottom the number falls again and that of *Gl. bulloides* rises.

Sta. 134 : *Gl. crassa* is absent from the top and bottom of the core, but present in the centre part, being most abundant at 29·0 cm., where the number of *Globigerina bulloides* is smallest.

Sta. 135 : *Gl. crassa* is uncommon in this core, occurring at two levels only, in both of which *Globigerina bulloides* is common.

Globorotalia menardii (d'Orbigny).

This is the commonest species of *Globorotalia* and is next in abundance to *Globigerina bulloides*. It is present in all the samples examined, usually in considerable numbers. It is essentially a tropical species.

Range of numbers 18–450 per 1000.
Mean 185.

The mean figures for each station indicate that the species is commoner in the deposits from deep water. This is almost certainly due to the greater resistance of these large tests to decay and solution. The mean numbers are given below :

Station	119	127	128	132	134	135
Mean	82	181	264	137	301	108

There is a very marked inverse fluctuation of this species compared with *Globigerina bulloides*.

Sta. 119 : There is a marked fall in numbers at 33·0 cm. Above and below this level the species is very common.

Sta. 127 : A marked fall in numbers occurs at 51·0 cm.

Sta. 128 : No less than four minima occur at 0, 22·0, 87·0 and 130·5 cm., at all of which levels *Globigerina bulloides* is abundant.

Sta. 132 : There is a decrease in numbers at 6·0 and again at 108·0 cm. It is most abundant at 45·0 cm., where fewest *Globigerina bulloides* occur.

Sta. 134 : In the top and bottom portions of the core this species and *Globigerina bulloides* seem to fluctuate in the same direction, but between 5·0 and 59·5 cm. the fluctuations of the two species are inverse. The number of specimens varies only slightly in the upper half of the core ; it is considerably less in the lower half.

Sta. 135 : *Gl. menardii* is rather less common than at other stations. It is more abundant in the lower half of the core. The fluctuations are opposite to those of *Globigerina bulloides* in the upper half of the core ; but in the lower half the numbers increase continually to the bottom of the core.

Globorotalia truncatulinoides (d'Orbigny).

This is a rather rare species, present in about one half of the samples. It is a tropical form.

Range of numbers 0–39 per 1000.
Mean 5.

The species is commoner in the Somali Basin than on the eastern side of the Arabian Sea, as the following numbers show :—

Station	119	127	128	132	134	135
Mean	9	2	9	4	0	0

Fluctuation in the numbers of the species are generally opposite to those of *Globigerina bulloides.*

Sta. 119: It is entirely absent at 33·0 cm., where *Globigerina bulloides* is abundant.

Sta. 127 : It is very rare. The largest number occur at 51·0 cm.

Sta. 128 : Correlation with the numbers of *Globigerina bulloides* is bad. Fewer specimens occur with the first decrease in *Globigerina bulloides,* an increased number with the second, and the third is doubtful, as *Gl. truncatulinoides* is rare in the lower half of the core. There is a very distinct maximum at 22·0 cm.

Sta. 132 : The species is absent from the two upper levels and rare in the lowest, in all of which *Globigerina bulloides* is abundant.

Stas. 134, 135 : The species is absent from Sta. 134 and practically so from Sta. 135.

Globorotalia tumida (Brady).

This species is next to *Gl. menardii* in order of abundance in the genus, but is much less common. It also is found in tropical waters.

Range of numbers 0–181 per 1000.
Mean 38.

It is generally distributed, being rather more frequent in the western part of the sea.

Station	119	127	128	132	134	135
Mean	25	44	83	7	36	4

Sta. 119 : There is the usual fall in numbers at 33·0 cm.

Sta. 127 : The maximum occurs at 25·0 cm., corresponding to the minimum of *Globigerina bulloides,* and two minima at 51·0 and 96·5 cm., where *Gl. bulloides* is commonest.

Sta. 128 : The numbers fluctuate inversely to those of *Gl. bulloides* in a marked degree. Smaller numbers occur at 22·0, 65·5 and 130·5 cm. as compared with the intervening levels.

Sta. 132 : Decreases in numbers occur at 6·0 and 108·0 cm.

Sta. 134 : Numbers are higher in the centre of the core, falling considerably at the two extremities. The drop in numbers at 107·5 cm. is considerable.

Sta. 135 : Very few specimens occur in this core.

From the foregoing data an idea of the distribution of the tests of pelagic species in the deposits of the Arabian Sea, and some of the species themselves, can be obtained. The apparent distribution of various species is shown in Table III.

TABLE III.—*Range of Distribution of Species.*

	Evenly distributed.	Mainly western part.	Mainly eastern part.	Deep water (> *c.* 4000 m.).	Shallow water (< *c.* 3000 m.).
	Globigerina bulloides *Globigerinoides sacculifera* *Pulleniatina obliquiloculata* ? *Globorotalia canariensis*	*Globigerina dubia* *Globigerinoides conglobata* *Orbulina universa* *Globorotalia crassa* *Gl. truncatuloides* *Gl. tumida*	*Globogerina inflata* *Globigerinella æquilateralis* *Gl. digitata*	*Sphæroidinella dehiscens* *Globorotalia menardii*	*Globigerinoides rubra* (*Pulleniatina obliquiloculata*) (*Orbulina universa*)
Total	4	6	3	2	1 (3)

The first three columns in all probability indicate real geographic distribution of species. The fourth and fifth columns probably show the distribution of dead tests only, and are probably due to differential destruction of the tests of the species. The one species found chiefly in shallow water, *Globigerinoides rubra*, has a small delicate test, unlikely to survive a long slow descent through the water without damage. The specimens of *Gl. rubra* identified were always complete tests, no fragments were found. Once broken it is probable that dissolution is rapid. Consequently, tests are to be expected only in comparatively shallow water. *Orbulina universa* and *Pulleniatina obliquiloculata* also show a tendency to collect in shallow water. This again is to be correlated with a rather delicate test. In *Orbulina universa* the spherical test is very thin, with large perforations, and is easily crushed, as is evident from the few whole tests, but many fragments, that are present. The smooth polished test of *Pulleniatina obliquiloculata* appears solid enough, but many of the specimens exhibit considerable erosion of the surface, and are very soft and crumble when touched. Evidently these two species do not survive a long passage to the bottom, but are broken up and probably dissolved on the way down.

The two " deep-water " species, *Sphœroidinella dehiscens* and *Globortalia menardii* exhibit the opposite characteristics. In both the test is massive and not easily broken. Consequently the tests tend to accumulate on the bottom and in deep water, owing to the solution of the more delicate forms, comprise a greater proportion of the deposit than of the living population of pelagic Foraminifera.

The proportions of each species in the deposit are thus, in part, at least, determined by selective destruction and hence differ from those of the living individuals occurring at the surface of the sea. Because of this the proportions found in one core are not strictly comparable with those found in another if the depths of deposition differ substantially. The depths from which four of the present cores come are within a range of 174 m. and thus are comparable. The other two, from Stas. 119 and 135, are from much shallower water, and so might be expected to contain more of the more delicate forms, though movement of the deposit by currents probably destroys considerable numbers.

From the stratigraphical standpoint the most important changes are those at successive levels in the deposit. Depth and selective destruction do not matter here, as the materials to be compared come from the same core and are only separated by a few centimetres vertically. Accordinlgy more reliance can be put upon such comparisons than upon horizontal ones. The main assumption made is that the relative rates of solution of the tests have been the same since the lowest part of the core was deposited.

Further to illustrate the difficulty of correlating the cores Table IV may be cited. This shows the mean numbers of each species at successive levels for all six cores, the samples being grouped over short vertical depth-ranges. It has already been seen that individual cores show stratification in the numbers of individual species. In this table, however, these variations are less apparent, being smoothed out in averaging the samples. Only two *Globigerina bulloides* maxima occur as against three if the cores are taken separately. The explanation that there is no real stratification in the cores, the apparent stratification being due to sampling errors, is eliminated by the existence of visible signs of stratification, as at Sta. 119. The true explanation is probably that the rate of deposition varies with each region and deposit, so that comparable horizons are not quite at the same depths below the deposit surface. This is more likely, as the rate must be influenced by many factors, such as proximity to land and consequent abundance or lack of inorganic material,

abundance of remains of organisms, depth, solution, currents and no doubt other factors. Furthermore the tops of the cores do not represent the deposit surface, as variable amounts are lost from each during collection. These factors are apparently sufficient to eliminate evidence of the third peak of *Gl. bulloides*, which is less pronounced than the others. Hence in considering the stratification and variations in numbers of Foraminifera, each core must be treated separately.

TABLE IV.

Depth in core. (cm.)	*Globigerina bulloides.*	*Globigerina dubia.*	*Globigerina inflata.*	*Globigerinoides. conglobata.*	*Globigerinoides rubra.*	*Globigerinoides sacculifera.*	*Globigerinella æquilateralis.*	*Globigerinella digitata.*	*Orbulina universa.*	*Pulleniatina obliquiloculata.*	*Sphæroidinella dehiscens.*	*Globorotalia. canariensis.*	*Globorotalia. crassa.*	*Globorotalia menardii.*	*Globorotalia truncatulinoides.*	*Globorotalia tumida.*	Benthic spp.
0	536	68	15	26	25	23	2	1	11	53	14	0	6	152	4	37	29
4–6	485	69	14	23	16	26	2	3	13	69	9	3	8	193	2	52	14
22–33	482	86	19	15	17	18	1	5	17	62	8	2	20	206	4	35	8
51–65	515	88	16	12	24	12	5	1	21	59	10	2	15	175	6	24	19
90–96·5	481	73	33	5	3	9	5	1	10	37	14	1	13	246	3	48	20
107·5–113	469	66	51	9	17	12	15	2	11	71	8	0	5	201	1	38	25

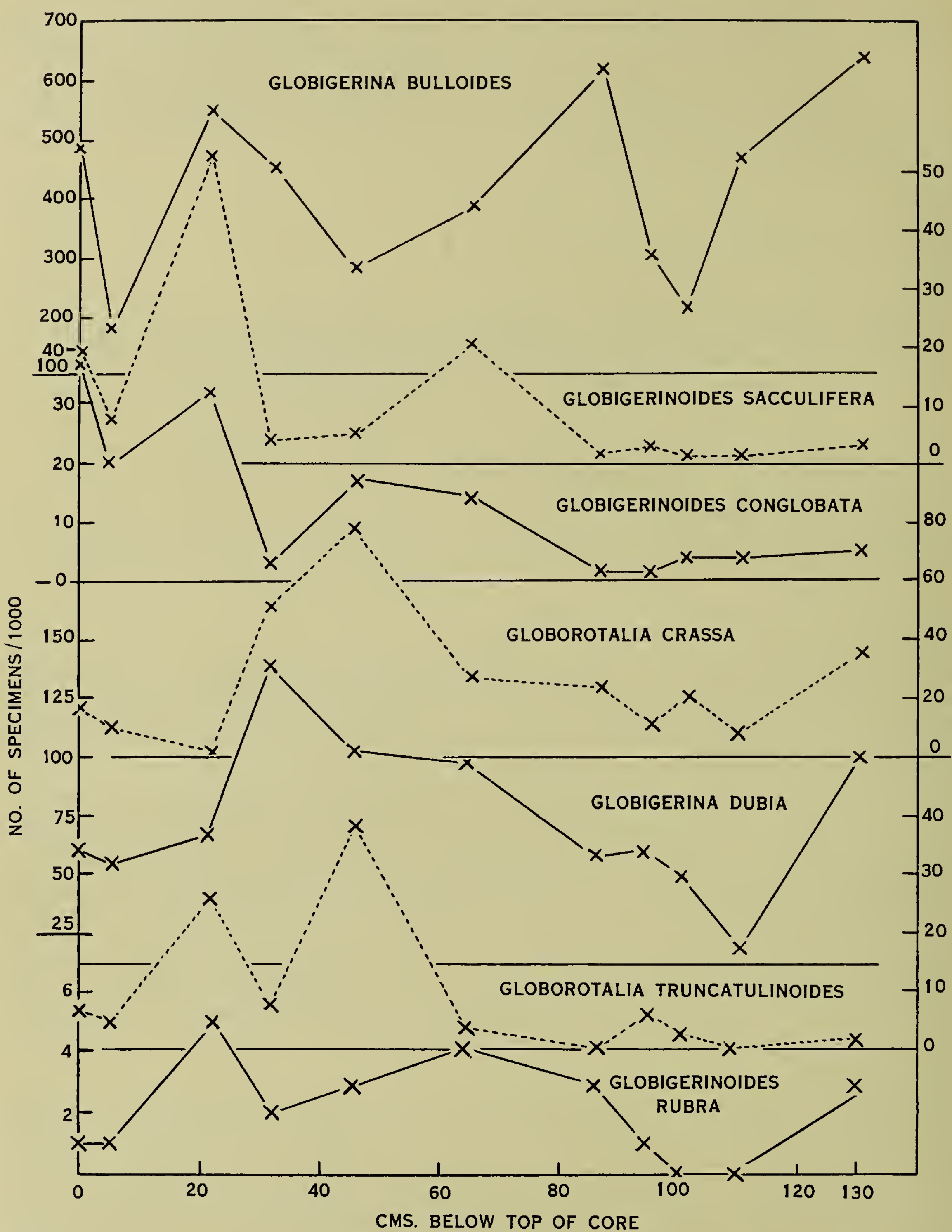
The foregoing statements of the fluctuations of the several species may now be summarized. It is seen that a few species agree with *Globigerina bulloides* in some parts of the cores, but not at all levels. Many more species fluctuate in the opposite direction while a number may vary irregularly.

In the following graphs (Text-figs. 1 and 2) thirteen of the species found at Sta. 128 have been plotted. The other three species are very rare. It is seen that *Gl. bulloides* stands practically alone. *Globigerinoides conglobata*, *Gl. sacculifera* and *Gl. rubra* (Text-fig. 1) agree fairly closely with it in their fluctuations, but their maxima tend to occur at slightly different levels to those of *Globigerina bulloides.* The initial fall from 0 to 5·0 cm. is not shown by *Globigerinoides rubra* ; this species shows the final rise at the bottom of the core as does *Globigerina bulloides.* The other two species of *Globigerinoides* do not. The position of the third high value varies. In *Globigerina bulloides* it is at 87·0 cm. In *Globigerinoides sacculifera* and *Gl. rubra* the corresponding peak occurs at 65·0 cm. and in *Gl. conglobata* at 46·0 cm.

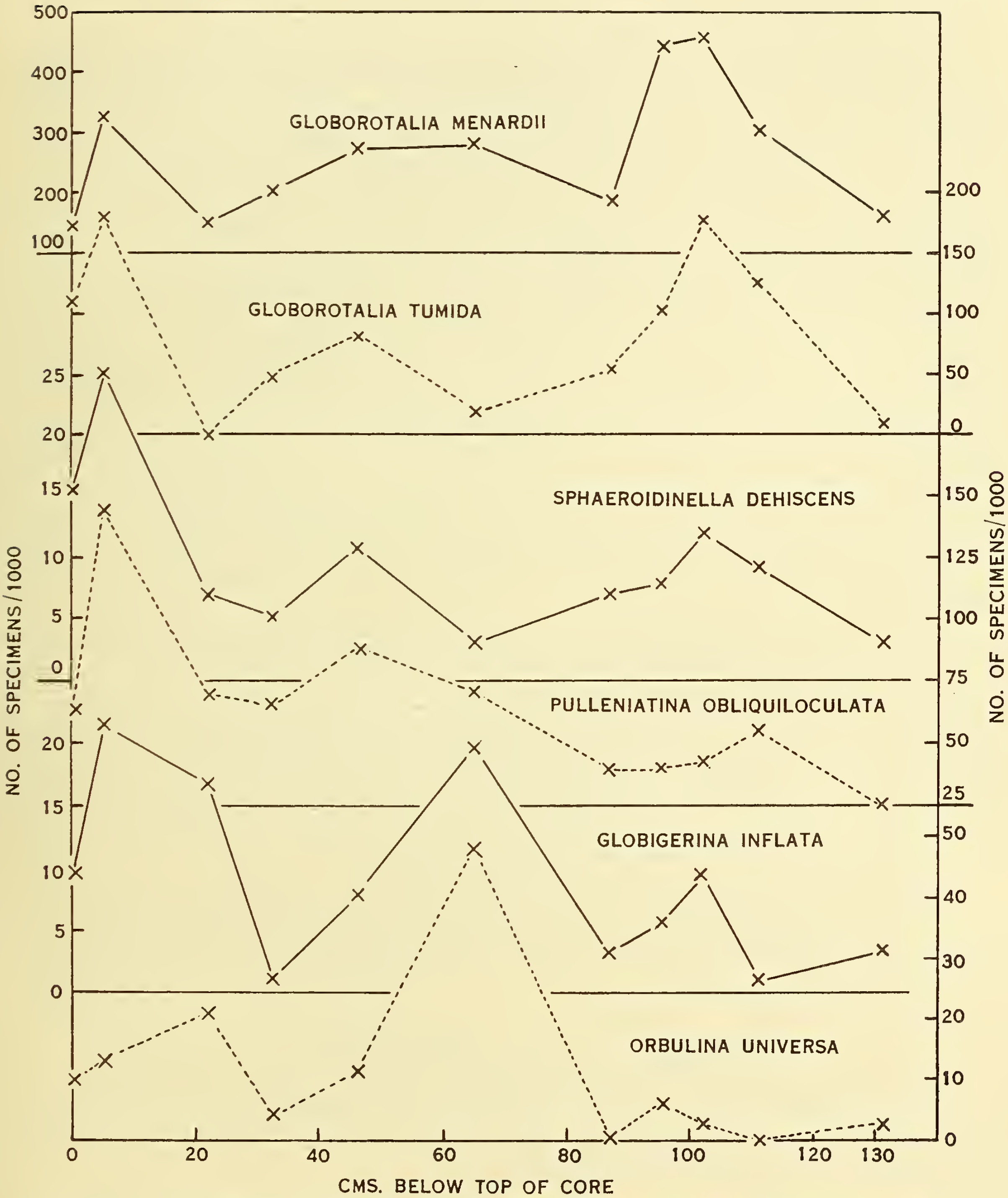
Globigerina dubia shows a well-defined peak at 32·5 cm. and the final rise. This peak probably corresponds to the second of *Gl. bulloides. Gl. dubia,* however, does not show a well-defined third peak. Instead the curve descends in a series of steps from the peak at 32·5 cm. to a minimum at 110·5 cm., and then rises to a final high value at 130·5 cm.

Globorotalia crassa shows a rather similar curve to *Globigerina dubia,* though there is a smaller variation in numbers between 65·0 cm. and the bottom of the core.

The curve for *Globorotalia truncatulinoides* shows three maxima, of which the first agrees in position with the second of *Globigerina bulloides.* The second is much nearer the first than in this latter species. The third also is at a higher level than in *Gl. bulloides.* This species, in company with *Globigerinoides conglobata* and *Gl. sacculifera* shows only minor



Text-fig. 1.—Frequency curves for the *Gl. bulloides* group of species. (The vertical scales to the right of the diagram refer to the curves drawn in broken lines; those on the left to the curves in plain line.)



TEXT-FIG. 2.—Frequency curves for the *Globorotalia menardii* group of species. (The three vertical scales to the right of the diagram refer to the curves drawn in broken lines; those on the left to the curves in plain line.)

fluctuations below 95·0 cm. There is no peak corresponding to the high value of *Globigerina bulloides* at the surface.

The six species shown in Text-fig. 2 show much greater agreement.

These species show maxima where the foregoing showed minima. Each of the species, *Globorotalia menardii*, *Gl. tumida*, *Sphœroidinella dehiscens*, *Orbulina universa*, *Pulleniatina obliquiloculata* and *Globigerina inflata* shows three maxima. Except for a slight divergence in the case of *Orbulina*, these maxima are at practically the same level for all species.

According to Philippi (1910, p. 568) all the species shown in the two graphs are found mainly in equatorial waters. The three exceptions are *Globigerina bulloides*, *Gl. inflata* and *Globorotalia crassa.* On this grouping these three would be expected to show similar fluctuation curves. Actually they do not agree very closely. The curves of *Globigerina bulloides* and *Globorotalia crassa* bear some resemblance to one another, but that of *Globigerina inflata* is quite different. This curve agrees with those of essentially tropical species. *Gl. inflata* is as widely distributed and penetrates as far into high latitudes as *Gl. bulloides.* Like the latter species it is said to be essentially a cold-water form. It has already been stated that it is not very common in the Arabian Sea, though *Gl. bulloides* is often abundant. This suggests that its fluctuations are not entirely due to temperature conditions. The presence of large numbers of *Gl. bulloides* may restrict its numbers, perhaps by reducing the available food supply. How far the interrelations of all the species affect the numbers of each it is impossible to say, but there is doubtless some measure of competition between the species.

The majority of pelagic species have a very wide range of distribution north and south of the equator. Thus *Globigerina dubia*, said by Philippi to be a warm-water species, is recorded by Brady (1884, p. 595) as occurring as far north as 56° N. lat., and as far south as 46° S. lat. It is thus difficult, if not impossible, to draw a hard and fast line between warm- and cold-water species. A species may penetrate much farther north in the Atlantic Ocean than, say, in the Pacific, depending upon the temperature of the water mass in which it is drifting. Moreover, many species must find their optimum conditions somewhere between the two extremes of heat and cold. It is possible that those species giving intermediate curves, *e.g.*, *Orbulina universa* and *Globorotalia crassa*, are such.

The above graphs (Text-figs. 1 and 2) illustrate all the common species at one station only. Very similar fluctuations occur at the other stations from which the same types of curve can be drawn.

IV. THE BENTHIC FORAMINIFERA.

Benthic Foraminifera are not very abundant in the deposits except in a few surface samples, notably from Stas. 119 and 134. They occur at all levels examined. The variations in numbers per 1000 tests are shown below :

Range 3–73.
Mean 17.

The actual numbers per 1000 tests at each station and level examined are shown in the last column of Table I. They represent all species present, whether identified or not. The commoner species alone have been identified and appear below under their respective stations and levels.

STATION 119.

0 cm. : *Rhabdammina abyssorum, Rh. discreta, Rh. linearis, Marsipella elongata, Tholosina bulla, Hyperammina friabilis, Dendrophrya ramosa, Reophax nodulosus, Ammodiscus incertus, Ammodiscoides turbinatus, Ammolagena clavata, Cyclammina compressa, Verneulina propinqua, Triloculina* sp., *Pyrgo depressa, P. murrhina, Lenticulina subalata, Dentalina filiformis, Nonion umbilicatulum* and *Bolivinita quadrilatera.*

4·5 cm. : *Reophax* sp., *Textularia ? concava, T. gramen, Gaudryina robusta, Clavulina parisiensis, Quinqueloculina* sp., *Sigmoilina schlumbergeri, Triloculina trigonula, Pyrgo depressa, Robulus* sp., *Dentalina communis, Saracenaria italica, Lagena marginata, Nonion umbilicatulum, Bulimina elegans, B. ovata, Uvigerina aculeata, U. asperula, Eponides haidingeri, Epistomina elegans, Ceratobulimina contraria, Cassidulina subglobosa, Planulina ariminensis* and *Cibicides lobatulus.*

10·5 cm. : *Textularia* sp., *Pyrgo murrhina, Lagena marginata, Nonion pompilioides, Elphidium crispum, E. jenseni, Bulimina aculeata, Uvigerina pygmæa, Rotalia* sp. and *Cassidulina subglobosa.*

33·0–33·5 cm. : *Pyrgo depressa, Ophthalmidium inconstans, Robulus* sp., *Cassidulina subglobosa* and *Chilostomella ovoidea.*

47·5–48·0 cm. : *Ophthalmidium inconstans, Lagena marginata, Uvigerina asperula* and *Cassidulina subglobosa.*

58·5–60·0 cm. : *Pyrgo murrhina, Robulus* sp., *Lagena marginata, Nonion umbilicatulum, Bulimina aculeata, Uvigerina asperula, U. pygmæa, Ceratobulimina contraria* and *Cassidulina subglobosa.*

65·0 cm. : *Gaudryina baccata, G. robusta, Clavulina communis, Quinqueloculina* sp., *Massilina arenaria, Sigmoilina schlumbergeri, Pyrgo depressa, P. lucernula, Robulus* sp., *Nodosaria* sp., *Nonion umbilicatulum, Uvigerina aculeata, U. asperula, Eponides haidingeri, Epistomina elegans, Ceratobulimina contraria* and *Cibicides lobatulus.*

STATION 127.

0 cm. : No benthic species.

4·0–4·5 cm. : *Reophax nodulosus, Lagena longispina, Virgulina subsquamosa, Cassidulina subglobosa* and *Planulina wuellerstorfi.*

25·0–26·5 cm. : *Verneulina bradyi, Lagena marginata* and *Virgulina subsquamosa.*

51·0–52·5 cm. : *Nonion pompilioides.*

86·5–88·0 cm. : *Pyrgo murrhina, Nonion pompilioides* and *Planulina wuellerstorfi.*

96·5–98·5 cm. : *Robulus* sp., *Lagena marginata* and *Cassidulina subglobosa.*

STATION 128.

0 cm. : *Verneulina bradyi* and *Rotalia* sp.

5·0–5·05 cm. : *Pyrgo depressa, Robulus ? gibbus, Rotalia* sp. and *Laticarinina pauperata.*

22·0–23·5 cm. : *Lagena marginata, Uvigerina asperula* and *Cassidulina subglobosa.*

32·5–34·0 cm. : *Pyrgo murrhina, Robulus* sp., *Lagena marginata, Lagena* sp., *Virgulina subsquamosa, Uvigerina asperula, U. pygmæa, Cassidulina subglobosa* and *Chilostomella ovoidea.*

46·0–46·5 cm.: *Verneulina bradyi, Gaudryina baccata, Pyrgo murrhina, Nonion umbilicatulum, Uvigerina pygmæa* and *Rotalia* sp.

65·5–67·0 cm.: *Pyrgo murrhina* and *Uvigerina pygmæa.*

87·0–89·0 cm.: *Pyrgo murrhina, Dentalina* sp., *Nonion umbilicatulum, Bulimina ovata* and *Chilostomella ovoidea.*

95·0–96·5 cm.: *Gaudryina baccata, Pyrgo murrhina, Uvigerina asperula* and *Cassidulina subglobosa.*

101·5 cm.: *Pyrgo murrhina, Lagena* sp., *Nonion umbilicatulum, Uvigerina pygmæa, Rotalia* sp. and *Cassidulina subglobosa.*

110·5–112·0 cm.: *Pyrgo murrhina, Lagena marginata, Nonion pompilioides, Uvigerina asperula* and *Cassidulina subglobosa.*

130·5–132·0 cm.: No benthic species.

Station 132.

0 cm.: *Verneulina bradyi, Pyrgo murrhina, Lagena seminiformis* and *Nonion pompilioides.*

6·0–8·0 cm.: *Pyrgo murrhina* and *Chilostomella ovoidea.*

26·5–28·0 cm.: *Pyrgo murrhina, Nonion pompilioides, Virgulina subsquamosa, Uvigerina asperula, Chilostomella ovoidea, Planulina ariminensis* and *P. wuellerstorfi.*

45·0–47·0 cm.: *Planulina wuellerstorfi.*

63·0–64·5 cm.: *Pyrgo murrhina.*

91·0 cm.: *Pyrgo murrhina.*

108·0–109·5 cm.: *Pyrgo murrhina, Nonion pompilioides* and *Rotalia* sp.

Station 134.

0 cm.: *Virgulina subsquamosa.*

5·0–6·0 cm.: *Reophax* sp., *Haplophragmoides ? latidorsatus, Nonion pompilioides, N. umbilicatulum* and *Rotalia* sp.

29·0–30·5 cm.: *Pyrgo murrhina, Nonion pompilioides* and *N. umbilicatulum.*

59·5–61·0 cm.: *Lagena marginata, Glandulina rotundata, Nonion pompilioides, Uvigerina pygmæa, Rotalia* sp., *Cassidulina subglobosa, Planulina ariminensis* and *P. wuellerstorfi.*

90·0 cm.: *Textularia agglutinans, T. porrecta, Verneulina bradyi, Triloculina oblonga, Pyrgo murrhina, Nonion pompilioides, Uvigerina asperula, Gyroidina soldanii* and *Planulina wuellerstorfi.*

107·5 cm.: *Textularia agglutinans, Pyrgo depressa, P. murrhina, Lagena alveolata, L. lævis, Nonion pompilioides* and *Uvigerina asperula.*

Station 135.

0 cm.: *Rotalia brœkhiana* and *Planulina wuellerstorfi.*

6·0–7·5 cm.: *Hyperammina friabilis, Glomospira charoides, Clavulina communis, Pyrgo murrhina, Lagena marginata* and *Planulina wuellerstorfi.*

33·5–34·5 cm.: *Gaudryina baccata, Pyrgo murrhina* and *Planulina wuellerstorfi.*

61·0 cm.: *Pyrgo denticulata, P. murrhina, Lagena alveolata, Uvigerina pygmæa* and *Rotalia brœkhiana.*

86·0–88·0 cm.: *Verneulina bradyi*, *Nodosaria* sp., *Lagena marginata*, *Uvigerina pygmæa* and *Laticarinina pauperata*.

113·0 cm.: *Pyrgo murrhina*, *Lagena marginata*, *Planulina wuellerstorfi* and *Laticarinina pauperata*.

All the commoner species are listed above. The number of species present at any one station is small except at Sta. 119, where the number is more than double that at any other station. The numbers at each station are :

Station	119	127	128	132	134	135
No. of species	56	10	19	10	21	14

The presence of this large number of species at Sta. 119 is doubtless due to the shallower habitat. A large number of the species are forms commonly met with near land and in green mud. It is of interest to compare the species met with in the upper and lower layers of Globigerina ooze in this core. Twenty species occur in the surface deposit. At 4·5 cm., still in the Globigerina ooze, twenty-three species occur, but only two of these, *Pyrgo depressa* and *Nonion umbilicatulum*, are common to both levels. In the lower Globigerina ooze, from 60·0 cm. to the bottom of the core, seventeen species occur. This layer has the same two species in common with the surface deposit, but no less than twelve in common with the 4·5 cm. layer, including *Pyrgo depressa* and *Nonion umbilicatulum*.

The intermediate mud-layer, 9·0–60·0 cm., is very poor in species. Only seven were identified ; two, *Ophthalmidium inconstans* and *Chilostomella ovoidea*, occur here only in this core. One, *Cassidulina subglobosa*, occurs also in the 4·5 cm. layer. *Pyrgo depressa* is found at all levels and a species of *Robulus* in the 4·5 cm. sample and the bottom layer as well.

At all other stations there seems to be only a slight correspondence in species at different levels. The possibility that this is due to the very small number of tests present in any one sample must not be excluded. That so many are common to the bottom layer and to the 4·5 cm. layer at Sta. 119 is further evidence of the remarkable similiarity of these two deposits here. From the different species found in the surface deposit, as compared with the 4·5 cm. level, it is evident that there has been a big change in the benthic Foraminiferal fauna during the period of deposition of the top 4·5 cm. of the core. It is remarkable that there is no similar change in the pelagic fauna between these two horizons. Despite the almost complete change of species there is scarcely any change in the total number of benthic Foraminifera present.

The top and bottom layers at Sta. 134 have only one species, *Nonion pompilioides*, in common. At other stations too few species are present for comparison.

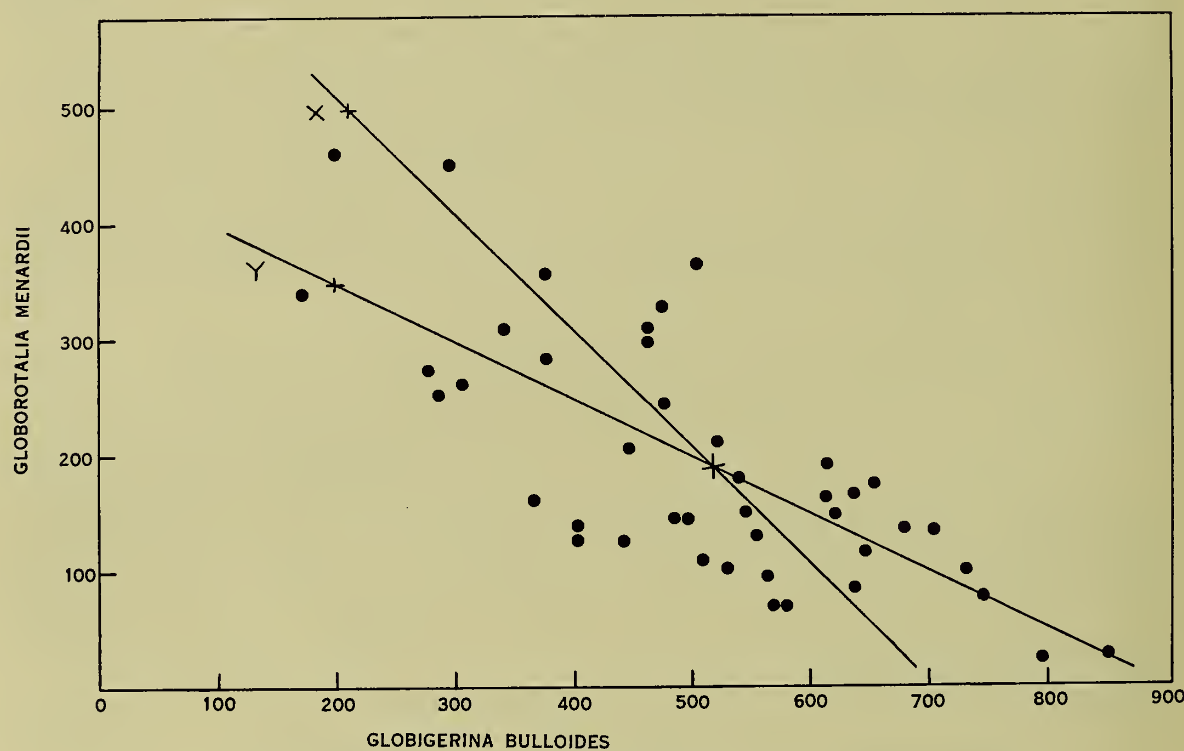
Table V.

6 stations.	5 stations.	4 stations.	3 stations.
Pyrgo murrhina	*Verneulina bradyi*	*Virgulina subsquamosa*	*Pyrgo depressa*
	Lagena marginata	*Uvigerina asperula*	*Robulus* sp.
	Nonion pompilioides	*U. pygmæa*	*Nonion umbilicatulum*
		Rotalia sp.	*Planulina ariminensis*
		Cassidulina subglobosa	*Chilostomella ovoidea*
		Planulina wuellerstorfi	*Gaudryina baccata*

There is very little correspondence between the species found at successive peaks in a core, or between those found at the corresponding peaks in different cores. There is, likewise, little similarity between the total Foraminiferal faunas at different stations. Very few species occur at more than two stations. Seventy-one species were identified, of which those listed above (Table V) occurred at more than two stations.

V. THE RATIO BETWEEN *GLOBIGERINA BULLOIDES* AND *GLOBOROTALIA MENARDII.*

In comparing the cores it is sufficient to use only a few of the species as indicators of conditions. *Globigerina bulloides* and *Globorotalia menardii,* as the two commonest, at once suggest themselves. The former species is mainly an inhabitant of cold water, whereas the latter is restricted to tropical and subtropical waters. Moreover, from the counts made there seems to be an inverse relationship between these two species. Statistical treatment shows that this relationship is real. The regression lines for the two species are shown in Text-fig. 3.



TEXT-FIG. 3.—Regression of *Globigerina bulloides* (X) and *Globorotalia menardii* (Y).

The regression coefficients of the two species are :

Globigerina bulloides —1·0.
Globorotalia menardii —0·49 ;

and the standard errors of these coefficients—

Globigerina bulloides 0·151,
Globorotalia menardii 0·072.

The evidence of a population ratio between the two species is thus conclusive.

These species are sufficient to show the trends of climatic conditions in the past. Because of this relationship it is possible to combine the numbers of the two species as a ratio of one to the other. The ratio *Globigerina bulloides*/*Globorotalia menardii* is adopted here. Table VI shows this ratio at all the levels examined in each core. Text-fig. 4 shows these values plotted against the corresponding depths below the tops of the cores. The peaks indicate large numbers of *Globigerina bulloides* relative to *Globorotalia menardii*, and therefore, cold conditions. Low values indicate that *Gl. menardii* is more abundant and that conditions during deposition were warmer.

Table VI.

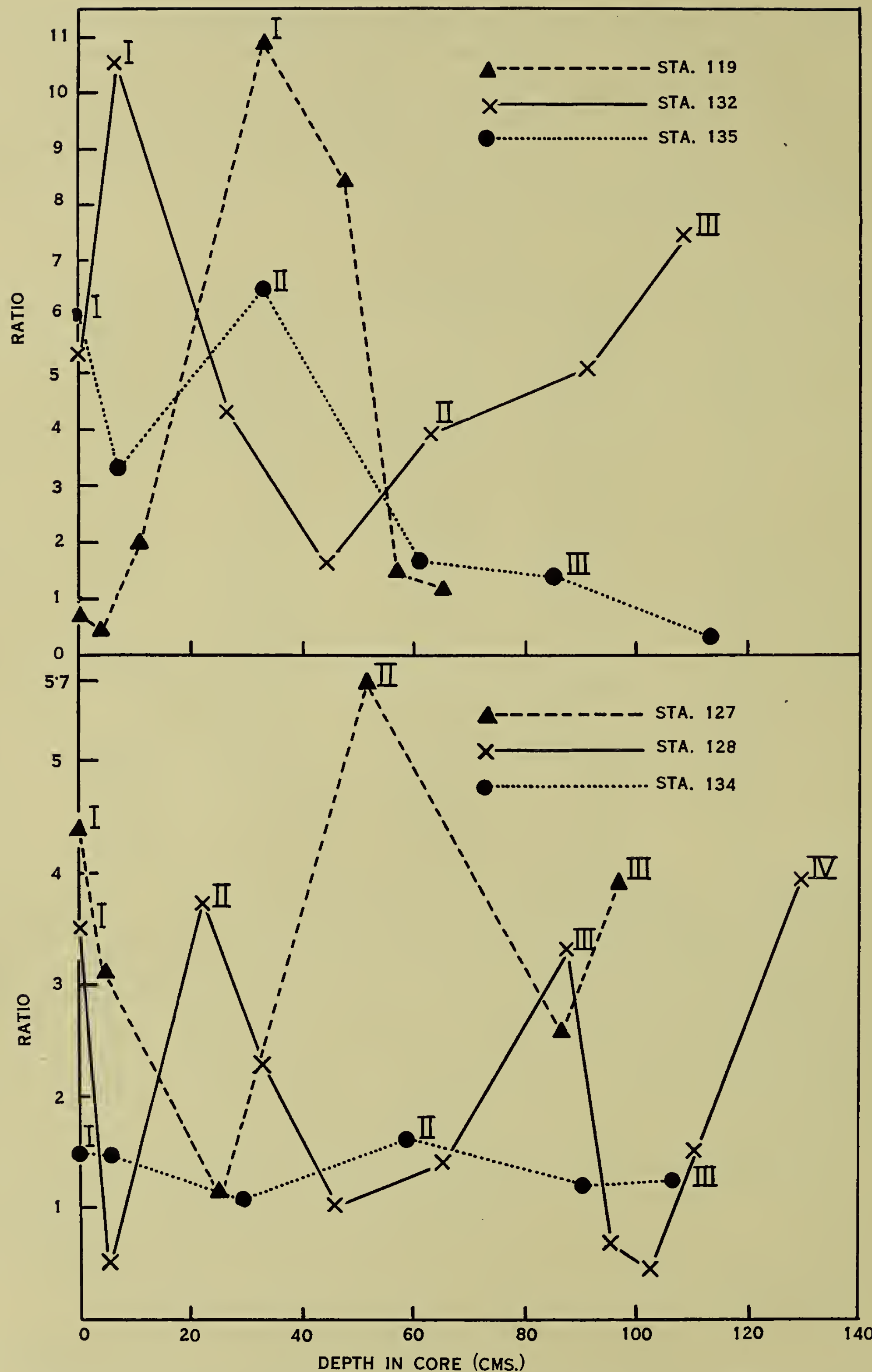
Station.	Cm.	Ratio.	Cm.	Ratio.	Cm.	Ratio
119	0	3·24	33·0	44·22	65·0	4·88
	4·5	3·15	47·5	3·39	..	..
	10·5	7·88	58·5	6·20	..	..
127	0	4·41	25·0	1·15	86·5	2·54
	4·0	3·13	51·0	5·69	96·5	3·92
128	0	3·52	46·0	1·05	101·5	0·46
	5·0	0·53	65·0	1·39	110·5	1·54
	22·0	3·72	87·0	3·30	130·5	3·94
	32·0	2·28	95·0	0·68	..	..
132	0	5·40	45·0	2·03	108·0	7·58
	6·0	10·20	63·0	4·03	..	..
	26·5	4·38	91·0	5·23	..	..
134	0	1·51	29·0	1·08	90·0	1·19
	5·0	1·47	59·5	1·61	107·5	1·23
135	0	8·10	33·0	8·64	86·0	3·54
	6.0	5·39	61·0	3·69	113·0	2·43

The ratio curves for the different cores are described below.

Sta. 119 : The graph of the *Gl. bulloides*/*Gl. menardii* ratio for this core shows low values in the upper layers and at the bottom of the core. The ratio reaches a very high value within the intermediate mud layer, due to increased numbers of *Globigerina bulloides* and very few *Globorotalia menardii*. This is what would be expected if the mud-layer was deposited under cold conditions. This core is short and the graph shows only the one peak.

Sta. 127 : This core is 96·5 cm. long. Reference to Table I and Text-fig. 4 shows that there are three peaks, at 0, 51·0 and 96·5 cm. The first most probably corresponds to that at Sta. 119. The difference in level is no doubt in part due to loss of the surface of the core. The second peak at 51·0 cm. probably indicates an earlier cold period not represented in the core from Sta. 119. Although that core goes down to a depth of 68·5 cm. the faster rate of deposition in shallow water may explain why the second zone was not reached at this depth. The final rise of the curve at 96·5 cm. indicates a third cold period.

Sta. 128 : This is the longest core obtained. Four cold periods are represented in its length. The first at the top of the core, corresponds to that seen at the surface in the cores from Stas. 119 and 127 ; that at 22·0 cm. corresponds to the second at Sta. 127. Two further peaks at 87·0 and 130·5 cm. appear to indicate still earlier cold periods unrepresented in the preceding cores.



TEXT-FIG. 4.—Ratio *Globigerina bulloides*/*Globorotalia menardii* plotted against depth.

Sta. 132 : The first peak occurs at 6·0 cm. and corresponds to the first one in the three preceding cores. There is a slight break in the slope of the curve at 63·0 cm., probably indicating the second cold period. A definite peak at 108·0 cm. most probably corresponds to the third cold period. Its depth agrees with this interpretation, as it is reasonably near the position of the third peak at Stas. 127 and 128. Conditions in this region must have changed far less during the second cold period, as there is very little change in the pelagic fauna compared with the changes noticeable at Stas. 127 and 128.

Sta. 134 : Only very small fluctuations are detectable in this core. Without reference to the other cores it might be assumed that the graph of the ratio was a horizontal straight line. By comparison with the others, however, it is seen that the ratio rises slightly at depths corresponding to peaks in the graphs of the other cores. Slight increases in the ratio at 0 and 59·5 cm. appear to correspond to the first and second peaks of the other cores. A third rise is very doubtful. The ratio increases very slightly from 90·0 to 107·5 cm., so there may be a third peak below this depth in the deposit at this station, but the Bigelow tube penetrated no deeper. The top part of the core is evidently lost.

Sta. 135 : This core shows the first two peaks distinctly. The third is indicated by a break in the slope of the curve at 86·0 cm. The upper few centimetres of ooze appear to have been lost.

The six cores thus show up to a maximum of four zones in which the ratio is high. The position of these zones in the cores is summarised below, Table VII, together with the total lengths of the cores.

TABLE VII.

Station.	Length (cm.).	No. of zones.	Depths of zones (cm.).			
			1st.	2nd.	3rd.	4th.
119	68·5	1	33·0	..	..	..
127	96·5	3	0	51·0	96·5	..
128	132·0	4	0	22·0	87·0	130·5
132	116·0	3	6·0	63·0	108·0	..
134	118·0	3	0	59·5	107·5	..
135	120·5	3	0	33·0	86·0	..

It is convenient to begin the discussion with a consideration of the core from Sta. 119. As already stated (p. 162), this core has a stratum of calcareous mud enclosed between two strata of Globigerina ooze. It is apparent that conditions must have been very different during the period of deposition of this mud from what they were at an earlier period, or are at the present time. This middle stratum contains a considerable amount of clayey material and is evidently of terrigenous origin. There can be little doubt that this layer was deposited under conditions similar to those described by Philippi (1910) and Wüst (1933). That is to say, it is of glacial age. Being from a tropical locality it is not composed of glacial material, but is a water-borne detrital sediment. Its deposition far from land is due to the high precipitation during the pluvial period in these regions and the consequent strong flow of sediment-laden water into the sea. The scarcity of the warm-water species, *Globorotalia menardii*, supports this supposition.

This core forms a basis for correlating the others as the time of deposition of the mud zone can be determined approximately.

Schott (1935) has already correlated the stratified deposits of the Central Atlantic with the Ice Age, and has deduced rates of deposition of the various deposits as follows :

		Globigerina ooze.	Blue mud.	Red clay.
Rate in cm./1000 years.	maximum	2·13	3·3	1·33
	mean	1·2	1·78	0·86
	minimum	0·53	0·9	0·5

Using the figures for Globigerina ooze, it is possible to determine the time required to deposit the upper layer of Globigerina ooze at Sta. 119. There are 9·0 cm. of this ooze ; at the above rates this gives the following periods of time necessary for deposition :

Rate cm./1000 years.	Time (years).
2·13	4,200
1·2	7,500
0·53	17,000

Thus at the minimum rate of deposition the last of this mud layer was deposited about 17,000 years ago, *i.e.*, at about the end of the last glacial epoch, which is estimated to have been about 20,000 years ago. Taking into account the rather indefinite amount of ooze lost from the top of the core and the fact that the rate of deposition is not likely to have been exactly that found by Schott for the Atlantic, the figure of 17,000 years can be altered to 20,000 without loss of accuracy. The addition of only 1·5 cm. of ooze to the top of the core, at the above minimum rate would have raised the estimate of time to almost exactly 20,000 years.

Thus, on Schott's calculations, at least 10·0 cm., and at most 43·0 cm., of Globigerina ooze must have been deposited since the end of the glacial epoch. A high rate of deposition probably only occurs in regions where terrigenous as well as pelagic material is being deposited. Hence the amount of post-glacial material deposited in these cores would not be expected to reach the latter figure. The Foraminifera ratios in the cores examined, with the exception of those from Stas. 119 and 132, show maxima at the present surface due to the loss of the tops of the cores, *i.e.*, of the post-glacial deposit. Presumably these peaks should lie at least 10·0 cm. below the surface in intact, uncompacted cores. That much, if not all, of the post-glacial layer is lost is evidence of the slow rate of deposition of the ooze. Where deposition was more rapid, *e.g.*, Sta. 119, the upper maximum of the ratio is some distance below the present core surface. At Sta. 132 apparently less material was lost, or else deposition was faster in this region. Either cause will explain the initial rise in the curve between 0 and 6·0 cm.

Apart from the peak in the core from Sta. 119, which core is scarcely uniform with the others, the positions of the various peaks correspond fairly well. The range in depth of each is as follows :

Peak.	Range. (cm.)	Average. (cm.)
1	0–6.0	1·2
2	22·0–63·0	45·7
3	86·0–108·0	97·0
4	130·5	130·5

The first peak occurs uniformly at 0 cm. except at Sta. 132.

The second peak ranges over 41·0 cm. in the five cores in which it occurs. This is the greatest range of all. The peak occurs three times between 51·0 and 63·0 cm., but the other two levels are much nearer the surface, at 22·0 and 33·0 cm.

The third peak has a much narrower range of 22·0 cm.

Apparently, between the second peak and the third the rate of deposition was much the same at Stas. 127, 132 and 134, but was considerably greater at the other two, especially at Sta. 128. Between the first peak and the second the rates seem to be reversed. Here the shortest columns of ooze separate the peaks at Stas. 128 and 135, and very much longer ones at the other stations. The amounts of material deposited between the peaks are shown in Table VIII.

TABLE VIII.

Station.	Distance between peaks. 1–2 (cm.)	2–3 (cm)	3–4 (cm)
127	51·0	45·5	..
128	22·0	65·0	..
132	57·0	45·0	..
134	59·5	48·0	..
135	33·0	53·0	43·5
Average	44·5	51·3	43·5

The horizons representing the peaks of the ratios are thus fairly evenly spaced, being on the average a little short of 0·5 m. apart.

It is thus possible to correlate the first peaks in all the curves, and to date them as of glacial age. The repetition of similar phenomena at regular intervals in the cores is suggestive of regularly occurring cold periods, and it is justifiable to assume that these peaks indicate the most extreme periods of successive glacial epochs, or perhaps the colder periods of one glacial epoch.

The deposits of the Arabian Sea thus reflect the climatic conditions of the past in the same way as those of the Atlantic Ocean.

VI. SUMMARY.

Stratigraphical investigations have been made into changes in the fauna of six cores from the Arabian Sea.

The pelagic and benthic Foraminifera have been identified and the relative numbers of each species determined, the benthic species being grouped together, as they are rather infrequent. The number of each species fluctuates considerably from level to level.

An inverse relationship is demonstrable between the numbers of *Globigerina bulloides* and *Globorotalia menardii*, the two commonest species. As *Globigerina bulloides* is mainly a cold-water species and *Globorotalia menardii* an inhabitant of tropical and subtropical waters, it is possible to use these species as a guide to changes in climatic conditions in the past.

In each core the ratio of *Globigerina bulloides* to *Globorotalia menardii* shows well-marked fluctuations, corresponding to changes in climatic conditions. High values for the

ratio indicate relatively large numbers of *Globigerina bulloides* and consequently cold conditions, probably glacial. No less than four such " cold zones " are present in the longest core obtained. The intermediate zones of the cores with relatively more *Globorotalia menardii*, and, therefore, a smaller ratio, represent warmer interglacial periods.

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THE DISTRIBUTION OF ORGANIC CARBON AND NITROGEN IN SEDIMENTS FROM THE ARABIAN SEA

BY

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AND

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WITH TWO TEXT-FIGURES

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I. INTRODUCTION.

Comparatively little work has been done on the organic content of marine sediments, and few attempts have been made to correlate the results with the productivity of the sea measured by actual plankton hauls or derived from chemical studies. Although much work has been done on soluble nutrients, little is known about the organic content of marine sediments—a situation which is difficult to understand, since the regeneration of organic matter in the sea-bottom is of special importance to those who are interested in the nitrogen cycle, and to the ecologist the question as to whether this organic matter is inert or is available as a nutrient for bottom fauna and bottom-inhabiting bacteria is a problem of special interest. In addition the oil geologist is interested in the potentiality of recent sediments as source beds, and in general it would seem likely that the more organic matter such a sediment contains the more likely it is to be a source bed. The hydrographical and hydrological conditions suitable for the deposition of sediments rich in organic matter are of interest to the geologist, as he hopes by a study of these to obtain a clearer picture of the conditions under which oil-bearing strata were laid down. It is therefore the primary object of this report to record the chemical estimations of carbon and nitrogen determined on sediments from the Arabian Sea, largely collected by the John Murray Expedition, 1933–34, and then to attempt the interpretation of these results. It must, however, be emphasized that this work should be regarded as preliminary owing to the stations being far apart, and the impracticability (this investigation was only a part of a more detailed chemical study subsequently to be published) of checking the conclusion by studying sediments from other oceans. It is to be hoped that future expeditions studying the productivity of the oceans will not ignore the information which may be obtained from the sediments, and will collect bottom samples with all possible oceanographical data. By this means more useful results will be obtained, and these will undoubtedly be helpful in the interpretation of other problems.

In the following pages a brief historical survey will first be given, and then the description of the chemical methods and a record of the analyses; but before attempting a discussion of the results it will be necessary to explain the factors governing the productivity of the sea as a whole, and the conditions favourable to the formation of marine deposits rich in organic matter.

II. HISTORICAL SURVEY.

The information available from older investigations is largely based on determinations of loss on ignition, but since marine deposits contain considerable amounts of uncombined and crystal-lattice water as well as sea-salts and carbonates any determinations based on loss on ignition must lead to inaccurate results, even if due allowance is made for decomposed carbonates. One of the first investigators to realize this was Sir John Murray (1891), who considered that loss on ignition cannot entirely be attributed to organic matter ; and with the object of determining the nature of organic matter, carbon and nitrogen were estimated in a Globigerina Ooze (Challenger Station 224, 1850 fathoms) from the West Pacific Ocean. The figures given are C 2·80%, N 0·785%, giving a very low C : N ratio of 3·6. Murray concluded that an albuminoid substance is present, whilst Von Gümbel (1888) suggested that the organic content was made up of both albuminoid and fatty substances. Gazert (1912) studied the sediments collected by the German South Polar Expedition, and stressed

the relation between the amount of organic matter and the number of organisms. The chemical estimations were done by Gebbing (1909), who determined the total loss on ignition and made corrections for the loss of carbon dioxide and sodium chloride. Values found varied from 0·7% to 4·5%, the latter occurring in a Red Clay.

Boysen Jensen (1911*a*) estimated carbon and nitrogen in several bottom samples from Danish waters, as well as in eight samples collected by the Ingolf Expedition. A sand from the North Sea contained on a dry basis (100° C.) 0·34% organic carbon, and 0·027% nitrogen. The carbon content of bottom samples from various parts of Liim Fjord varied from 0·58% to 4·3% with a C : N ratio of 8·1 to 12·4. The clay bottom of the Kattegat, at depths of 30 to 35 metres, contained 2·3% carbon, with a C : N ratio of 11·5, while the mud from Roskilde Fjord contained as much as 10·2% carbon. Boysen Jensen (1914), finding that planktonic matter contained 50% carbon, suggested the factor 2·0 for calculating the amount of organic matter from organic carbon, but the use of this factor implies that there is no decided change in the balance of the various chemical constituents during the transformation of plankton, algal material, and other marine forms of life into marine humus.

Moore (1930) estimated the organic matter in the muds of the Clyde Area by their nitrogen content, and investigated the variations with depth. In general there was a fall of nitrogen with increasing depth in the sediment, though at a few stations a rise was recorded. The fall of nitrogen, according to Moore, might be accounted for by the breaking down of the organic nitrogenous compounds into nitrates and nitrites, and the removal of these into the water above.

In a series of determinations of organic carbon content of marine sediments collected in the Channel Islands Region, California, Trask (1931*b*) reported that the organic carbon content ranges from 0·4% in a near shore sand to 4·2% in a clay at the bottom of the Santa Cruz basin, and he concluded that the organic content follows the bottom configuration, being high in the depressions and low on the ridges. In a more detailed communication Trask (1932*a*) has collected together carbon and nitrogen determinations on approximately 100 marine sediments from the Channel Islands area and other coastal regions, as well as giving the nitrogen content of many oceanic samples.

Waksman (1933*a*), studying the abundance and distribution of organic matter in marine sediments off the east coast of America, suggested that organic matter in marine sediments can be designated "marine humus", thereby making it comparable to soil humus. The organic matter was calculated from the organic carbon content, which was determined by Tiurin's (1931) modification of Schollenberger's method. The nitrogen determinations were made by the Kjeldahl method. A series of mud samples taken from several stations in the Gulf of Maine shows little variation at each station when the samples are not taken too far apart, but when the samples are taken at greater distances the humus content shows considerable variations. Determination of the organic content in cores up to 112 cm. long showed in general a gradual but slow reduction with depth, but in one case there was an increase with depth. Only a few bottom cores at greater distances from shore were investigated; one taken by the "Nautilus" expedition north of Spitzbergen, and the others taken by the "Atlantis" on a cruise to Bermuda in September, 1932. The organic carbon content of the marine mud north of Spitzbergen is 0·85%, whilst four samples collected by the "Atlantis" varied between 0·35% and 0·46%.

Gripenberg (1934*a*) determined organic matter in a series of sediments from the North

Baltic. The organic carbon was determined by combustion *in vacuo*, the CO_2 evolved being absorbed by N/10 barium hydroxide. In order to obtain the organic content, Gripenberg multiplied the organic carbon percentage by the factor 1·724. The greatest deviation between two single analyses, according to the author, was 0·1%, corresponding to a deviation of approximately 0·05% in the organic carbon content. The nitrogen analyses on the Baltic samples were done by Wasastjerna, according to the micro-Kjeldahl method. Nitrogen determinations were considered good if they did not differ by more than 0·03% from each other. In the Baltic it was found that the late glacial and the post-glacial sediments form two distinct groups, the glacial sediments containing much less organic matter owing to excessive supply of inorganic detritus formed by the action of the ice sheets on the underlying bed rock. In addition Gripenberg investigated the variations of organic matter with depth, and found that down to depths reached by the sampler (about 20–35 cm.) late glacial clays had a fairly uniform organic content, but for the post-glacial sediments the analyses seem to indicate that the organic matter within the first 20 cm. of the bottom decreases with depth in the sediments of the Bay of Bothnia, but increases with depth elsewhere in the investigated area. It is suggested that this increase with depth is due to changed conditions of sedimentation.

Most extensive determinations of organic carbon were carried out by Correns (1935, 1937*a*) on the "Meteor" cores. In his report carbon determinations are recorded from 100 stations, situated in the equatorial regions of the Atlantic Ocean. In addition the variation of carbon in the deeper portions of the core samples was investigated, but unfortunately no nitrogen determinations are available on any of the "Meteor" samples. The "Meteor" results, although extensive and of great interest, are on this account of limited value. Carbon was estimated by oxidizing it to carbon dioxide by means of chromic acid, and absorbing the liberated carbon dioxide. The carbon dioxide content was, after making allowance for the carbon dioxide present as carbonates, multiplied by the factor 0·471 to obtain the organic content of the sediment. A relation was established between the organic matter and the carbonate content of the sediments, the average value falling with an increase of the carbonate content. It was concluded that approximately 0·2% of organic matter is present in the binding material of foraminiferal shells. No sediments of high humus content were collected by the expedition, the organic carbon contents being consistently below 1%. Correns found no relation between the humus content of a sediment and the amount of oxygen present in the water, but he considered that this may be due to the relatively few determinations of oxygen immediately above the sea-bottom, as well as the interfering nature of other factors. It is pointed out that in regions rich in sea life the deposits should be rich in humus, provided the conditions of sedimentation are suitable for the retention of humus, and such a relation between the plankton distribution and the humus content exists in the Cape Verde region.

The Scripps Institute of Oceanography has investigated the nitrogen content of marine sediments from the Californian region, but their results are not published apart from a preliminary report (Moberg, 1937). In this report it is stated that there is, in general, an increase in the amount of nitrogen with increasing depth and distance from the shore up to more than 100 miles from land, after which there is a decrease at greater distances. Analyses of core samples show that the highest nitrogen values are found at the surface of the sediments, and within a core sample 50 cm. long, the content at the lower end falls to about two-thirds that found near the surface.

III. ESTIMATION OF ORGANIC MATTER IN MARINE SEDIMENTS FROM ORGANIC CARBON CONTENT.

So far no direct means of determining accurately the organic content of marine sediments has yet been devised. Soil chemists estimate the organic content of the soil by multiplying the organic carbon content by a factor, and in spite of considerable disagreement, there seems to be a preference for the factor 1·724, corresponding to 58% carbon in soil organic matter. Although the formation of organic matter in soils depends on many factors, such as the activity of various micro-organisms, temperature, moisture and aeration, yet the final product is of fairly constant composition. It could be argued, however, with some justification that the factor 1·724 is inappropriate for marine deposits because of the marked difference in chemical composition between land and marine plants. Boysen Jensen suggested the factor 2, but as we have mentioned above, this assumes that there is no change in the balance of the various chemical constituents during decomposition. The organic matter of marine muds collecting not far from the shore is undoubtedly partially of terrestrial origin, and consequently one might reasonably expect this organic matter to have a ligno-protein nature with high carbon content. On the other hand the residues of marine plants, largely consisting of carbohydrates with low carbon content, should lower the carbon content of organic matter. Investigations have therefore been carried out by various authors to determine the nature of marine organic matter, but these unfortunately are not wholly satisfactory. Waksman (1933*b*) treated marine mud with a 4% solution of NaOH, and by this means 70% of organic matter was abstracted. The abstracted material was made up of the following complexes: lignin 21·0%, protein 30·2%, hemicelluloses, etc., 18·8%. From these results it was tentatively computed that the percentage of carbon in the abstracted organic matter is about 53. If the carbon content of marine organic matter is 53% the factor to be used for calculating the organic matter from organic carbon content is 1·887 ; but this assumes that the percentage of carbon in the remaining 30% is the same as that in the abstracted portion.

Trask (1931*a*) uses the factor 1·7, Correns (1937*b*) the factor 1·73, Gripenberg (1934*b*) the factor 1·724. In this report the latter factor has been adopted, not because the authors believe that the chemical composition of marine organic matter is the same as soil humus, but because they consider that there is insufficient chemical evidence about the nature of marine organic matter, especially that occurring in deep water, to warrant the use of a factor different from that used by soil chemists. In this report stress is laid on the organic carbon content and not on the humus content, as the humus content of marine sediments is at present largely hypothetical.

IV. CHEMICAL METHODS.

As carbon is the major constituent of organic matter it affords the most desirable means of measuring the organic content, but unfortunately in sediments containing carbonates organic carbon cannot be determined directly, but is the difference between total carbon and carbonate carbon. It has therefore been suggested by some authors that nitrogen forms a more practical means, especially since the method is simple, rapid, and accurate. Trask (1932*b*) has adopted this method for his investigations dealing with the source sediments of petroleum, and he considers that the C : N ratio is approximately constant and

equal to 8·4. Assuming that the organic matter is 1·724 times the organic carbon, it follows that the organic content is about 14·5 times the percentage of nitrogen. In our investigations this method was not adopted. The amount of nitrogen in organic matter is relatively small, and consequently the factor by which it has to be multiplied is large, and if the C : N ratio is not constant in sediments considerable errors will be introduced. The authors of this report believe that this ratio is more variable than has previously been suggested, and it will be shown on a subsequent page that in sediments from the Arabian Sea this ratio varies between 4·9 and 34·2. In the sample with the low ratio the organic matter calculated from organic carbon is 0·97%, and calculated from nitrogen 1·67%, whilst in the sample with the larger ratio, the organic matter is 1·95% or 0·48%, depending upon whether it is calculated from carbon or nitrogen. The error introduced by calculating organic matter from nitrogen content may, therefore, greatly exceed the possible error in the determination of organic carbon. Although it is probable that the percentage of organic carbon in organic matter is not constant, it is nevertheless great and presumably always over 50%. In our opinion, organic matter is more accurately determined from organic carbon.

As a disadvantage of determining organic matter from organic carbon, it may be urged that if the carbonate content is high, decomposition by combustion may not be complete. This difficulty can easily be overcome by determining total carbon by a wet method, as was adopted in this report, or possibly by removing the carbonates before combustion. Wahnschaffe and Schucht (1924) suggest the use of sulphurous acid for this purpose. Gripenberg (1934*b*) followed this method, and treated the weighed samples a few times on a water bath with small portions of saturated sulphur dioxide solution, after which they were transferred into the combustion boat. It was found that the sum of the carbon dioxide from the organic matter and the carbonates was smaller than that found by direct combustion analysis; in other words, organic matter was lost during treatment. Gripenberg concluded that on the average samples which have been subjected to preliminary treatment with sulphurous acid lose about 0·25% organic carbon.

In our investigations organic matter was determined from organic carbon not only because we regard it as a more accurate method than multiplying the nitrogen by a large and uncertain factor, but also because we desired to investigate the variations of the C : N ratio in marine sediments, and determine whether such possible variations could be correlated with any oceanographical features.

For the determination of organic carbon both wet and dry combustion methods were tried. In the wet combustion method a mixture of chromic acid and phosphoric acid was used as an oxidizing agent (Harwood, 1933), and for dry combustion the sample was mixed with lead chromate or copper oxide and ignited in a combustion tube. In both methods the carbon dioxide evolved was absorbed in soda lime and weighed. The results obtained by the combustion method were all slightly lower than those from the wet method, and this difference was traced to carbon dioxide retained by lead chromate. The same difficulty was experienced when lead chromate was replaced by copper oxide. Consequently it was decided that the wet method was the more suitable both on account of the retention of carbon dioxide, and the danger of the incomplete dissociation of the carbonates in the combustion method.

The apparatus employed consisted of a 250 c.cm. round-bottomed Pyrex flask, fitted with a tap funnel head with side outlet tube. The side tube was connected to an empty

U-tube in order to catch the water condensing during distillation, and the other arm of the U-tube was connected with an absorption train. This consisted of:

(1) A bubbler with phosphoric acid containing a little chromic acid.
(2) A tube containing pumice impregnated with anhydrous copper sulphate to absorb any hydrochloric acid not already caught.
(3) A calcium chloride tube.
(4) Two weighed soda lime tubes.
(5) A calcium chloride guard tube leading to the pump.

About ½ grm. of the sample was weighed out into the dry flask and 3 grm. of chromic acid added. The tap and stopper of the funnel were lubricated with a drop or two of phosphoric acid and the apparatus fitted together. Twenty c.cm. of phosphoric acid were run slowly into the flask from the funnel and the flask gently heated. When most of the carbon dioxide from the carbonate had been evolved the heat was gradually increased until the contents of the flask turned green and the heating was continued for thirty minutes longer. The whole operation took about two hours. The flame was then extinguished and air drawn through the apparatus for twenty minutes. The soda lime tubes were removed and weighed after standing half an hour in the balance case. The blank, using A.R. materials, was generally not more than 2 mgrm.

The carbon dioxide associated with the carbonates was determined by a similar method using phosphoric acid alone and a simplified form of the apparatus. The difference between the two values gives the carbon dioxide from the organic matter, from which the organic carbon content of the sediment was calculated.

The method described above is long, but needs little attention, and was found to give quite satisfactory duplicate results. It was found unnecessary with these samples to pass the gas through a heated solution of mercuric oxide in phosphoric acid, as recommended by Dixon (1934) in the case of certain rocks and minerals.

Some typical duplicate results on samples containing varying amounts of organic matter are shown in Table I below.

TABLE I.

Sample.	Organic carbon.	Difference.
170 Globigerina Ooze	0·55, 0·57	0·02
160 Cream Mud	1·10, 1·01	0·09
114 Brown Mud	1·51, 1·55	0·04
179 Green Mud	2·15, 2·11	0·04
180 ,,	2·93, 2·92	0·01
55 Brown-green Mud	5·17, 5·21	0·04

In the above typical results the organic carbon content as determined by duplicate analyses differ from each other in all but one case by a smaller percentage than 0·05. The authors consider that in general the organic carbon analyses recorded in this report have an accuracy of ± 0·05%. Trask (1932*b*) considered that the probable error of any individual organic carbon determination was about 0·2%, but the methods he adopted were different from those used in our investigations.

Gripenberg (1934*c*) has suggested that marine samples when heated at a low temperature may lose part of their organic matter, and it is therefore of some importance to know whether on drying the samples at 105° C. in order to determine H_2O-, any appreciable organic matter is lost. To test this idea three green muds which contained considerable organic matter, and also gave a high loss at 105° C., were chosen, and organic carbon determined before and after drying at 105° C. The results obtained are shown in Table II.

TABLE II.

Sample.	Loss at 105° C.	Organic carbon before drying.	Organic carbon after drying at 105° C.
55 Green Mud	5·08	5·17 } 5·19	5·14 } 5·13
	5·08	5·21 }	5·12 }
66 ,,	4·12	4·73	4·78
56 ,,	3·48	3·57	3·49

In the above table the differences are within the limits of the experimental error of the carbon determinations, and these results would indicate that the loss of organic carbon at 105° C. has no appreciable effect on the accuracy of the H_2O- determination.

Nitrogen was determined in the samples by the micro-Kjeldahl method, and as the percentage of nitrogen is low, 0·2 grm. of the sample was weighed out on an ordinary balance, and the determination done in the usual micro-apparatus. Sodium selenate was used as a catalyst and N/100 hydrochloric acid and caustic soda for the final titrations. Determinations of nitrogen were made in duplicate and seldom differed by as much as $\pm$ 0·003%. In a few cases when the difference was more than this further determinations were made. Some typical results on samples of varying nitrogen content are shown in Table III.

TABLE III.

Sample.	Nitrogen.	Difference.
170 Globigerina Ooze	0·024	0·003
	0·027	
160 Cream Mud	0·060	0·001
	0·061	
85 Grey Clay	0·125	0·001
	0·124	
33 Green Mud	0·293	0·006
	0·287	
21 ,,	0·327	0·002
	0·325	
55 ,,	0·506	0·003
	0·503	

V. ANALYTICAL RESULTS.

For purposes of convenience the analytical results are tabulated in Table IV, the Murray Expedition Stations being arranged in order of increasing depth. In addition

a few samples from the British Museum collections have been investigated. In the first column the station number is given, and in those cases where the lower portions of the cores have been investigated the average depth from the top is recorded. In the second column the depth is given, in the third the latitude and longitude, and in the fourth the amount of organic carbon. During this investigation it was found that the H_2O- content of the samples did not remain constant even when the sample was stored in a well-corked bottle. It was therefore decided, in order to make the analyses more comparable, to recalculate the organic carbon content on a H_2O- and NaCl free basis. The results of this recalculation are given in the fifth column, whilst in the sixth the organic carbon is given on a $CaCO_3$, H_2O-, and NaCl free basis. The seventh column represents the amount of organic matter in the original sample, whilst in the eighth the amount of nitrogen in the original sample is recorded. Nitrogen is recalculated without H_2O- and NaCl in column 9, and in the tenth without H_2O-, NaCl, and $CaCO_3$. In the eleventh column C : N ratio is given, and in the twelfth the $CaCO_3$ present in the original sample. The thirteenth column represents the CO_2 content recalculated without H_2O- and NaCl, whilst in the fourteenth column the CO_2 is recalculated without organic matter, H_2O-, and NaCl.

Samples from 44 different stations were investigated, and in the lower portions of the cores determinations were made at 16 stations.

VI. FACTORS GOVERNING THE PRODUCTION OF ORGANIC MATTER.

Before attempting the interpretation of the above results it is necessary to discuss the factors which govern the productivity of the sea as a whole, especially as mineralogists and geologists are not normally acquainted with this subject. Although the productivity of the sea is ultimately responsible for organic matter in recent sediments, as well as in marine deposits of past ages, it is desirable to mention, in addition, the factors which govern the regeneration of organic matter and the subsequent dispersal of the regenerated nutrients.

(*a*) The Nitrogen Cycle.

It is well known that the sea in its upper layers supports a rich flora, and the immensely varied animal population is entirely dependent either directly or indirectly upon the flora for carbohydrates and proteins. Some of these animals feed on marine algae during the whole or part of their lives, whilst others are carnivorous, preying upon their neighbours and ingesting and feeding upon particles of dead organisms and bacteria. It follows, therefore, that marine plants exert a most powerful influence on marine fauna.

The larger marine algæ are sessile and are confined to a comparatively narrow zone around the coasts, and the maximum depth at which they are found varies with the depth to which light penetrates in appreciable quantities. Besides the fixed algæ very numerous small plants, mostly unicellular, and known as phytoplankton, occur in the upper illuminated layers of the sea. The depth to which phytoplankton grow and multiply rarely exceeds 150 metres, and on death or during old age they sink slowly, often with the formation of spores. Phytoplankton may be devoured by zooplankton or decomposed

Table IV.

Station No.	Depth (metres).	Latitude. °	′	″	Longitude. °	′	″	Organic carbon.	Organic carbon on a H_2O– and NaCl free basis.	Organic carbon on a H_2O–, NaCl and $CaCO_3$ free basis.	Organic matter.	Nitrogen.	Nitrogen on a H_2O– and NaCl free basis.	Nitrogen on a H_2O– NaCl and $CaCO_3$ free basis.	C : N.	$CaCO_3$.	CO_2 on a H_2O– and NaCl free basis.	CO_2 on a H_2O–, NaCl and organic matter free basis.
160 . .	37	4	52	30 N.	72	51	36 E.	1·06	1·11	13·82	1·83	0·061	0·064	0·795	17·1	87·78	40·44	41·23
73 . .	91	25	28	48	56	35	54	0·88	0·90	3·87	1·52	0·070	0·071	0·308	12·6	75·58	33·80	34·34
164 . .	183	8	15	24	73	01	30	0·55	0·56	14·87	0·95	0·043	0·044	1·162	12·8	94·12	42·32	42·73
70 . .	196	25	34	12	57	23	30	1·69	1·79	2·15	2·91	0·144	0·153	0·183	11·7	15·60	7·28	7·51
75 . .	201	25	10	48	56	47	30	2·15	2·28	4·61	3·71	0·218	0·232	0·468	9·9	47·56	22·21	23·12
106 Top . .	212	5	38	54 S.	39	15	42	1·49	1·58	4·76	2·57	0·110	0·117	0·352	13·5	62·79	29·36	30·18
106 (32¼ cm.) .	212	5	38	54	39	15	42	1·52	1·65	4·95	2·62	0·112	0·121	0·365	13·6	61·59	29·34	30·20
106 (54½ cm.) .	212	5	38	54	39	15	42	1·38	1·48	4·65	2·38	0·100	0·108	0·337	13·8	63·33	29·93	30·73
206 . .	256	13	57	30 N.	42	35	24	2·12	2·26	6·80	3·65	0·157	0·168	0·504	13·5	62·50	29·34	30·54
191 . .	274	13	46	30	47	48	54	2·17	2·24	4·34	3·74	0·203	0·209	0·406	10·7	46·91	21·27	22·13
179 . .	275	12	02	06	50	40	12	2·13	2·21	18·06	3·67	0·201	0·209	1·704	10·6	84·43	38·59	40·13
114 . .	353	5	06	08 S.	59	14	05	1·53	1·63	3·85	2·64	0·131	0·139	0·330	11·7	54·41	25·40	26·14
180 . .	366	12	03	24 N.	50	40	12	2·93	3·09	16·24	5·05	0·260	0·274	1·441	11·3	76·85	35·60	37·61
207 . .	375	14	08	56	42	19	00	2·85	3·06	8·82	4·91	0·207	0·222	0·640	13·8	60·75	28·71	30·31
56 . .	421	22	12	42	59	51	18	3·57	3·92	6·73	6·16	0·293	0·322	0·552	12·2	37·93	18·33	19·65
64 . .	448	24	47	00	61	21	18	0·53	0·54	0·62	0·91	0·101	0·104	0·118	5·2	12·10	5·45	5·50
66 Top . .	609	23	44	24	58	40	00	4·73	5·35	8·26	8·16	0·382	0·432	0·667	12·4	31·11	15·48	17·06
66 (43 cm.) .	609	23	44	24	58	40	00	4·27	4·62	6·99	7·36	0·283	0·306	0·463	15·1	31·34	14·91	16·20
55 . .	794	22	07	30	59	52	12	5·19	5·79	7·92	8·95	0·505	0·564	0·770	10·3	24·06	11·80	13·11
117 . .	889	3	38	48 S.	40	23	42	1·87	2·03	4·28	3·22	0·127	0·138	0·290	14·7	48·51	23·13	23·96
65 . .	907	25	02	12 N.	59	40	30	3·28	3·49	4·09	5·65	0·292	0·310	0·364	11·2	13·96	6·53	6·94
20 Top . .	1132	11	54	12	45	16	30	4·43	4·76	10·55	7·64	0·346	0·372	0·824	12·8	51·00	24·12	26·28
20 (41¼ cm.) .	1132	11	54	12	45	16	30	2·39	2·51	6·79	4·12	0·158	0·166	0·449	15·1	59·91	27·70	28·96
119 Top . .	1204	6	29	24 S.	39	49	54	1·16	1·24	3·13	2·00	0·058	0·062	0·157	20·0	56·61	26·58	27·16
119 (31¼ cm.) .	1204	6	29	24	39	49	54	1·70	1·89	2·99	2·93	0·111	0·123	0·195	15·4	33·13	16·19	16·73
119 (66¾ cm.) .	1204	6	29	24	39	49	54	1·05	1·14	2·83	1·81	0·054	0·059	0·145	19·4	54·71	26·19	26·73
33 Top . .	1295	13	41	00 N.	48	17	00	3·17	3·34	6·80	5·47	0·290	0·306	0·622	10·9	48·22	22·37	23·73
33 (37½ cm.) .	1295	13	41	00	48	17	00	2·15	2·26	5·22	3·71	0·160	0·168	0·389	13·4	53·86	24·92	25·92
21 Top . .	1518	11	18	36	45	05	18	4·29	4·62	11·04	7·40	0·326	0·351	0·838	13·2	54·03	25·57	27·77
21 (38¾ cm.) .	1518	11	18	36	45	05	18	4·78	5·25	8·71	8·24	0·412	0·452	0·751	11·6	36·24	17·50	19·24
85 . .	1687	19	24	54	69	18	48	2·06	2·20	4·25	3·55	0·125	0·133	0·258	16·5	45·39	21·27	22·11
63 . .	1703	24	37	18	63	07	36	1·16	1·20	1·39	2·00	0·134	0·139	0·161	8·7	12·87	5·88	6·00
62 Top . .	1893	22	53	30	64	56	10	1·23	1·29	1·79	2·12	0·122	0·128	0·178	10·1	26·57	12·27	12·55
62 (20¾ cm.) .	1893	22	53	30	64	56	10	0·81	0·84	1·41	1·40	0·046	0·048	0·080	17·6	39·33	17·86	18·13
59 . .	1948	22	22	48	60	06	24	2·61	2·79	4·40	4·50	0·253	0·270	0·427	10·3	34·41	16·14	16·95

26 Top . .	2312	12 29 30	50 51 30	2·63	2·86	5·90	4·53	0·232	0·252	0·521	11·3	47·46	22·69	23·86
26 (30½ cm.) .	2312	12 29 30	50 51 30	1·59	1·69	5·06	2·74	0·119	0·126	0·379	13·4	62·90	29·33	30·21
26 (54½ cm.) .	2312	12 29 30	50 51 30	1·51	1·60	5·82	2·60	0·107	0·113	0·412	14·1	68·36	31·88	32·78
135 Top . .	2727	4 37 42 S.	72 35 36	0·93	0·98	7·40	1·60	0·034	0·036	0·271	27·4	82·58	38·17	38·83
135 (62¾ cm.) .	2727	4 37 42	72 35 36	1·04	1·10	3·49	1·79	0·054	0·057	0·181	19·3	64·80	30·13	30·71
135 (114¾ cm.).	2727	4 37 42	72 35 36	0·86	0·90	4·26	1·48	0·036	0·038	0·178	23·9	75·67	34·71	35·26
60 . .	3054	21 58 00 N.	62 19 42	0·70	0·72	1·09	1·21	0·052	0·054	0·081	13·5	32·84	14·86	15·05
76 . .	3289	24 10 36	59 00 36	1·24	1·29	1·47	2·14	0·140	0·145	0·166	9·0	12·05	5·50	5·62
81 . .	3351	23 17 06	61 00 36	1·22	1·28	1·46	2·10	0·155	0·163	0·185	7·9	11·62	5·37	5·49
170 . .	3676	7 38 48	58 18 30	0·56	0·58	3·72	0·97	0·026	0·027	0·173	21·5	81·60	37·12	37·50
92 . .	3722	16 09 36	68 50 54	1·29	1·34	3·26	2·22	0·055	0·057	0·139	23·5	57·03	25·94	26·56
93 Top . .	3991	14 24 24	66 12 42	0·71	0·74	2·00	1·22	0·045	0·047	0·127	15·8	60·64	27·75	28·10
93 (50 cm.) .	3991	14 24 24	66 12 42	0·57	0·59	0·93	0·98	0·039	0·040	0·063	14·6	34·97	15·95	16·12
93 (83¾ cm.) .	3991	14 24 24	66 12 42	0·67	0·72	0·97	1·16	0·052	0·056	0·075	12·9	24·24	11·39	11·53
167 Top . .	4042	7 11 48	63 05 36	0·45	0·47	1·74	0·78	0·034	0·036	0·132	13·2	69·85	32·10	32·36
167 (48¼ cm.) .	4042	7 11 48	63 05 36	0·31	0·32	0·98	0·53	0·026	0·027	0·082	11·9	64·21	29·43	29·60
167 (108¾ cm.).	4042	7 11 48	63 05 36	0·50	0·52	1·35	0·86	0·032	0·033	0·087	15·6	58·57	26·96	27·20
128 Top . .	4060	5 31 42 S.	49 33 30	1·01	1·07	3·98	1·74	0·039	0·041	0·154	25·9	68·69	32·10	32·71
128 (48¼ cm.) .	4060	5 31 42	49 33 30	0·78	0·82	4·87	1·35	0·022	0·023	0·137	35·5	79·47	36·60	37·13
128 (99 cm.) .	4060	5 31 42	49 33 30	0·59	0·63	2·51	1·02	0·023	0·024	0·098	25·7	70·46	32·98	33·34
132 Top . .	4082	1 01 24 N.	66 23 06	1·13	1·20	5·32	1·95	0·033	0·035	0·155	34·2	72·90	34·05	34·77
132 (48¾ cm.) .	4082	1 01 24	66 23 06	0·71	0·75	2·60	1·22	0·041	0·043	0·150	17·3	67·74	31·34	31·75
132 (114¼ cm.).	4082	1 01 24	66 23 06	0·77	0·81	3·04	1·33	0·034	0·036	0·134	22·6	69·81	32·27	32·73
127 . .	4091	7 32 24 S.	44 09 30	0·70	0·75	2·21	1·21	0·032	0·034	0·101	21·9	62·20	29·14	29·52
134 Top . .	4234	2 55 30 N.	70 05 30	1·20	1·31	3·32	2·67	0·053	0·058	0·147	22·6	55·81	26·68	27·30
134 (107½ cm.) .	4234	2 55 30	70 05 30	0·75	0·81	1·85	1·29	0·034	0·037	0·084	22·1	52·61	24·84	25·19
134 (118 cm.) .	4234	2 55 30	70 05 30	0·63	0·67	1·51	1·09	0·035	0·037	0·084	18·0	51·94	24·41	24·69
101 Top .	4285	1 25 00	47 37 48	1·50	1·64	2·73	2·59	0·110	0·120	0·200	13·6	36·50	17·56	18·06
101 (32¼ cm.) .	4285	1 25 00	47 37 48	1·07	1·14	2·82	1·85	0·059	0·063	0·155	18·1	55·84	26·17	26·70
101 (88¼ cm.) .	4285	1 25 00	47 37 48	1·52	1·64	4·55	2·62	0·077	0·083	0·231	19·7	59·53	28·17	28·98
166 Top . .	4793	6 55 18	67 11 18	0·76	0·83	0·85	1·31	0·030	0·033	0·034	25·3	2·36	1·14	1·15
166 (22¼ cm.) .	4793	6 55 18	67 11 18	0·65	0·70	0·72	1·12	0·037	0·040	0·041	17·6	1·87	0·88	0·90
166 (50¼ cm.) .	4793	6 55 18	67 11 18	0·67	0·72	0·74	1·16	0·042	0·045	0·046	16·0	1·50	0·71	0·72
166 (76¼ cm.) .	4793	6 55 18	67 11 18	0·49	0·53	0·54	0·84	0·046	0·050	0·051	10·7	2·14	1·02	1·03
M 4932 . .	3154	24 20 50	59 24 40	0·56			0·97	0·115			4·9	17·47		
M 7644 . .	3694	17 38 30	59 04 00	1·62			2·79	0·113			14·3	52·53		
M 7645 . .	3292	17 17 00	57 34 00	3·09			5·33	0·303			10·2	50·86		

by bacteria when falling to the sea-bottom, where they may be ingested by animals, decomposed by bacteria, or deposited in the sediments.

The breakdown of proteinaceous organic matter in soils by bacteria and the oxidation of ammonia through the intermediary of nitrite to nitrate has long been known, but this theory was not applied to the oceans until the close of the last century. In the sea neither animal nor plant life can use gaseous nitrogen : plant life depends for its growth upon the nutrient salts. In the photosynthetic zone of the ocean phytoplankton transform the soluble forms of nitrogen into complex organic forms, and during this process liberate oxygen. When the plants die, as well as the animals which feed upon them, nitrogen is brought again into solution in the form of ammonia, through the action of bacteria, but before the nitrogen is again assimilated by marine plants ammonia is oxidized first to nitrite and then to nitrate by the action of certain other bacteria. It is commonly regarded by oceanographers that the cycle nitrate ⟶ plants ⟶ nitrate is a closed one; but the occurrence of organic matter in the lower portions of cores, as well as its occurrence in geological formations, indicates that a certain proportion of nitrogen and carbon of the organic matter is not regenerated.

The classical series of experiments done at the Plymouth Laboratory (Atkins, 1923 ; Harvey, 1926, 1928 ; Cooper, 1933) have shown that there is a cycle in the amount of nutrient salts present in the English Channel, which corresponds with the annual cycle of phytoplankton. In the winter months there is a storing up of nutrient salts owing, as Harvey has suggested, to the lack of light limiting the growth of phytoplankton, and in spring the rapid outburst is conditioned by the increased amount of sunlight. This is followed by a rapid fall in the amount of nutrients in the sea-water.

Brand (1937*b*) has clearly demonstrated the regeneration of nitrogenous organic matter in sea-water. Using a natural source of organic plankton he found that the rate of decomposition was greatest in the first few days. Ammonia appeared in the water immediately decomposition commenced, and it reached a maximum at the end of plankton decomposition. The gradual disappearance of ammonia was accompanied by the increasing amount of nitrite, which in turn was oxidized to nitrate. Nitrate reached its maximum concentration after nitrite had commenced to disappear, and the regenerated nitrate supported a rapid growth of diatoms when inoculated with a fresh culture.

(*b*) Physical and Chemical Factors.

By far the most important factor which governs the production of phytoplankton is light, since the illumination below the surface of the ocean, owing to absorption by the water and scattering by the particles suspended in it, falls off rapidly with depth. Temperature does not inhibit the production of phytoplankton, as diatoms occur over a very wide range, but the Coccolithophoridæ which are characteristic of tropical waters are never found in temperate regions. Temperature, as Gilson (1937*a*) remarks, has an important indirect effect on the production of plankton, as the density difference between the surface layer warmed by the sun and the cooler water below prevents mixing across the discontinuity layer, and so cuts off the possibility of the nutrient salts becoming available from the deeper waters.

Nitrates, phosphates and silicates are most important for plankton production, as it

is on the supply of these, provided there is sufficient light, that the productivity of an area depends. During the rapid growth of plankton the supply of nutrients is rapidly depleted, and if these are not renewed in the surface layers (the means by which this is done will be discussed later) plankton production rapidly ceases. Harvey (1928) observed that in the English Channel when the supply of nutrients diminishes phytoplankton production rapidly falls off, and the work of the "Discovery" Investigations indicates that there is generally in the Antarctic a sympathetic relation between the silica content and phytoplankton production. Iron is another essential element for plant growth, since it is required in the formation of chlorophyll. Unfortunately very little is known about the distribution of iron in the seas. Thompson (1935) found the iron content in the water beyond the continental shelf to vary between 12 to 54 mgrm. per cubic metre, and Cooper (1935) considers that not more than 2 mgrm. Fe per cubic metre is in true solution. Since the iron content of phytoplankton is approximately four times the phosphorus content, Cooper suggests that during an outburst the iron requirements must be very great. The occurrence of trihydrone molecules, especially in Arctic waters, may possibly influence the growth of phytoplankton. In this connection Barnes (1932) found that *Spirogyra* grows more rapidly in water that had been recently frozen than in recently distilled water.

It has previously been remarked that during active plankton production the available nutrients in the upper layers rapidly decrease, and consequently an understanding of the renewal processes is of obvious importance if any attempt is to be made to correlate the abundance of organic matter in sediments with areas which from hydrological considerations are suitable for the renewal of surface waters.

During a period of production the dead plankton sink and carry out of the illuminated zone the nutrient substances so essential to plankton growth. The renewal of the surface water with nutrients could be brought about by the regeneration of the nutrients in the dead plankton and a subsequent upward circulation of the water, or by the incoming of river water rich in nutrients, or possibly by the atmospheric fixation of nitrogen. But as Brandt (1902) has pointed out, the abundance of nitrate in the deeper layers suggests that nitrification takes place at the sea bottom or close to it; so to-day the alternative hypotheses find little support.

In stable water conditions nutrients remain largely concentrated in a stable bottom layer, and the question arises as to how this stability is upset. In winter in both Temperate and Arctic regions the upper layers of the sea rapidly cool and the density increases; consequently unstable conditions are set up, and helped by the wind and the tide the whole body of the water may, in shallow water regions, become homogeneous from top to bottom. The nutrients now occurring in the top layer cannot, owing to the absence of sufficient light, be used until the next spring. In certain regions of the world a continuous supply of nutrients is made available by the upwelling of bottom waters, and these regions are likely to be stocked with abundant plankton—a fact which was recognized by Nathansohn (1906). In the North Atlantic, for example, this occurs where deep water runs up shallow plateaux, or where submarine ridges cause bottom currents to be deflected, as in the neighbourhood of the Faeroes (Gran, 1929). Alternatively supplies of nutrients may be brought by upwelling, as demonstrated by McEwen (1916). The theory of upwelling depends on the fact that a body is only in equilibrium with the earth's surface when at rest, but when set in motion the effect of the earth's rotation is to deflect the direction of its motion to the right of the force in the northern hemisphere and to the left in the southern

hemisphere. Suppose, for example, the wind to blow uniformly and in a direction parallel to the coast in the northern hemisphere. If the coast is on the left of the wind the surface water would be carried away from the coast, and the surface water would be inclined upward away from the coast, and thus would give a pressure gradient towards the coast. If the depth exceeds twice the depth of frictional resistance the resultant current would, according to Ekman (1923), consist of three parts : a pure drift current at the top flowing to the right, a current in mid depths flowing parallel to the coast, and a bottom current flowing towards the coast, the flow of which must be equal to that of the upper current. Consequently upwelling of bottom water would result. Such a circulation exists, for example, off the Pacific Coast of North America (Michael, 1921) and accounts for the abnormally cold water characteristics of these regions, but the more recent work of Sverdrup (1938) suggests that the process is far more complicated than was assumed on the basis of earlier data.

VII. FACTORS GOVERNING THE ACCUMULATION OF ORGANIC MATTER.

It has recently been suggested by Seiwell (1938) that " organic particles (having a density not greater than that of the bottom water) sinking through water of variable density will approach some level asymptotically, and if organic debris in the sea should be sufficiently homogeneous, a stratum of maximum oxygen consumption may be conceived of as occurring in the sea " through the accumulations of decomposing organic particles at a certain level. This proposed biological explanation of the oxygen minimum layer is opposed to the theory of Dietrich (1936) and Wüst (1936). According to Seiwell's calculations at " Atlantis " station 1170, organic particles of radius 0·0885 cm. will approach asymptotically a level of about 600 metres in 400 hours, while particles of 0·708 cm. will approach a level of 1950 metres in 200 hours. Parr (1939*a*), in a recent paper, points out that Seiwell's asymptotic approach theory depends upon the assumption that the density of the particle (p) remains constant and only the density of the sea-water (p′) changes with depth, and at the asymptotic level (p–p′) = 0, and he suggests that no reasonable or even possible thermal expansion coefficient for such particles would permit organic particles to find equivalent densities in the sea-water, at which such particles would accumulate.

If an attempt is made to calculate the rate at which organic particles sink several difficulties are encountered, since any calculations must ultimately depend upon Stokes's law,

$$v = \frac{2 . g\, r^2}{9\mu} (p-p'),$$

where v is the velocity of the settling particle of density p, r is its radius, and μ the viscosity of the sea-water of density p'. The formula stipulates that the particle should be spherical, but as this condition is obviously not fulfilled the term " equivalent radius " has been introduced by Odén. Further the particle will become smaller as decomposition proceeds, and the relation between $(p-p')$ and depth is completely unknown. Finally, although the viscosity of sea-water is known, and its variations with temperature and salinity (Krümmel, 1907), little is known of the effect of pressure.

Taking Seiwell's value 0·00242 for the difference of density between organic matter and sea-water, and assuming that this density difference remains constant (Parr, 1939*b*),

a particle of radius 0·1 cm. would take 17 days to sink at station 166 from 100 to 4793 metres. It has been assumed that since the effect of pressure on the viscosity of sea-water is unknown, the value of μ determined from the mean temperature and salinity of the water between 100 and 4793 metres is sufficiently accurate. If, however, the radius of the particle gradually decreases, the time taken to reach the bottom would be greatly increased, as the velocity of a falling particle is proportional to the square of the radius. Unfortunately, it is impossible to correct for this additional complication, as nothing is known about the size distribution of particulate matter in sea-water.

It is important to realize that even if the sea-bottom at one station contains more organic matter than at another, this does not necessarily imply that at the first station more organic material is deposited annually, as there may be relatively little inorganic matter deposited at the first place. In this connection Gripenberg (1934*d*) found that the late glacial muds of the Baltic contained less organic matter than the post-glacial, and suggested that this might be due to a decrease in the rate of sedimentation, though the increase in organic sedimentation may be partially due to the influence of the changing conditions at the commencement of post-glacial times. It is clear therefore that when attempting to correlate organic content of bottom sediments with the productivity of the sea, due consideration must be given to the possible variations introduced by differing rates of sedimentation.

As the density of particulate organic matter is approximately the same as that of sea-water, it is reasonable to expect organic matter to collect in regions characterized by mud deposits. One of the first to point this out was Boysen Jensen (1911*b*), who recorded high carbon contents from the muds of the Kattegat and low from the sands of the North Sea. This idea was further elaborated by Trask (1931*b*), who found a relation between the amount of organic matter and the submarine topography ; in the basins it is high and on the slopes it is lower. The grain size varies in a corresponding manner, being coarser on the ridge and finer in the basins. Whether this relation applies to regions away from the coast is unknown, and in our investigations insufficient mechanical analyses have yet been done to arrive at any definite conclusions.

A most important factor governing the accumulation of organic debris is biological activity, as much organic matter is consumed or regenerated long before it reaches the bottom. Brand (1937*a*, 1938) has reported that the amount of nitrogen in the particulate matter of sea-water varied from 0 to 47γ ($\gamma = 0{\cdot}001$ mgrm.) per litre. The greatest variations occurred in the upper 400 metres, and below this depth the amount is practically constant. It is suggested that these variations can be explained by differing living conditions in the two zones, as in the deeper layers conditions are practically uniform, resulting in relatively uniform and low nitrogen values owing to the absence of autotrophic organisms, apart from certain bacteria. The animals living in the deeper layers must depend for their food upon the remains and excreta of organisms living above, or possibly on bacteria (ZoBell, 1938), since Krogh (1934) has shown that dissolved organic nitrogen cannot be used appreciably by organisms. There is therefore an approach to a dynamic equilibrium, passing through many stages, between the particulate organic matter and living organisms. The excess organic matter is, of course, ultimately deposited in the sediments.

On the ocean floor a varied marine fauna, comprising representatives of all the major groups of marine animals, is present. At great depths complete darkness and very low

temperature retards the metabolism of the invertebrates, and it would seem that the number of individual animals living at great depths is very small.

In addition to the bottom-living animals, oceanic sediments support a large bacterial population. Certes (1884) found bacteria in all except four out of the 100 sediments collected at depths down to 5100 metres by the Talisman expedition, whilst Russell (1893) found 200 to 300,000 viable bacteria per c.cm. of bottom mud; the overlying water seldom contained more than 100 per c.cm. Waksman and his collaborators at Woods Hole (1933) have demonstrated the presence of bacteria in sea muds capable of oxidizing ammonium salts to nitrite, but they found it more difficult to demonstrate the presence of nitrate-forming bacteria. In addition nitrate-reducing bacteria were found, but most of these organisms reduce nitrate to nitrite and not to atmospheric nitrogen. It is important to know to what extent bacteria are able to attack organic complexes present in bottom sediments, and how readily the nutrient salts can be regenerated and thus made available for plant synthesis. With this object in view Waksman and Hotchkiss (1938*a*) investigated the oxidation of organic matter in marine sediments by bacteria. Earlier experiments (Waksman, 1933*c*) indicated that dried mud, under purely artificial conditions, when remoistened was capable of giving off part of its carbon and a smaller amount of nitrogen, thus proving that the organic matter is not absolutely inert, but is capable of being slowly decomposed. In the later experiments the availability or stability of organic matter in marine sediments was measured by the oxygen consumption in sea-water. It was found that in fresh marine sediments the organic matter is oxidized very slowly by bacteria, which is very different from the rapid oxidation of planktonic material under similar conditions (Waksman, 1938*b*). In the period of the experiment (15–30 days) nitrites and nitrates could not be found in solution, and the oxidation process was found to take place at the expense of the non-nitrogenous organic complexes. Sediments recovered from considerable depths contain organic matter which oxidizes much less readily than that occurring in near shore deposits, indicating that organic matter in sediments from great depths is much more resistant than in sediments from shallow water.

The vertical distribution of bacteria in sediments off the Californian coast has been studied by ZoBell and Anderson (1936). The distribution of bacteria is independent of depth within limits of the observations (depths to 2000 metres), the temperature of the ocean floor and the distance from the mainland, but the bacterial content is greatly influenced by the organic content of the sediments. The upper parts of the cores contain the richest bacterial population, the numbers rapidly decreasing with depth. At the surface of the mud aerobes were more plentiful than anaerobes, but in the subsurface strata the reverse is the case. Cognizance should, however, be taken of the fact when interpreting the result that many bacteria are facultative anaerobes. In sea-water bacteria are most abundant in the surface layers, where usually a few hundred are present per c.cm. At depths below 200 metres very few bacteria can be demonstrated, whereas at the bottom the quantity ranges from several thousand to several million per wet gramme. The preponderance of bacteria in the sea-bottom has been attributed to several factors, such as more favourable oxidation-reduction conditions, to absorption by marine muds, to greater freedom from bacteria feeders, to the lower rate of metabolism owing to the lower temperatures, and to the concentration of organic matter. In bottom sediments as well as in oceanic waters a state of equilibrium exists between bacterial multiplication and bacterial destruction, and a change in this equilibrium may be brought about by a change in food supply,

environmental conditions, or a modification of agents unfavourable to bacteria. ZoBell agrees with Reuszer (1933) that the evidence at present indicates that the presence of utilizable organic matter is the most important single factor which influences the distribution of bacteria, but he indicates that the rate of multiplication of bacteria in sea-water is several thousand times as great as that in freshly collected bottom samples.

VIII. DISCUSSION AND INTERPRETATION OF RESULTS.

(a) Distribution of Organic Matter.

The distribution of organic matter in the sediments from the Arabian Sea is most readily appreciated by reference to Text-fig. 1, where the organic carbon content of the sediments is recorded on a H_2O– and NaCl free basis. Although a more extensive investigation would have been desirable, the present results suggest a large central area extending into the Gulf of Oman, where the carbon content of the sediments is smaller than 1%. Surrounding this is a belt containing 1 to 1·5%, and then a rich coastal area. In attempting to correlate these results with the distribution of nutrient salts, the authors have found the report published by Gilson (1937*b*) to be of the utmost value, but before commencing a description of the areas, the effects of the S.W. monsoon should be understood. From May to September the monsoon may cause considerable mixing in the upper layers of the ocean. When calm conditions are resumed in September considerable growth of phytoplankton is initiated, but owing to the shortage of nutrient salts this is mostly over by the end of January. From this time onward plankton is comparatively sparse except when upward water movements cause renewal of nutrient salts. The large outburst of diatoms recorded by Menon (1931) off the Madras coast has been correlated with the rains brought by the S.W. monsoon.

(*a*) *The Gulf of Aden.*

The amount of organic carbon found in the sediments from the Gulf of Aden is high, and varies between 2·21% at station 179 and 4·76% at station 20. According to Gilson the section from Aden to Berbera is characterized in the month of September by a sharp discontinuity layer. The warm surface water was depleted of nitrate and approached saturation with oxygen, and in the lower layer nitrite reached a high value below the density boundary, owing to the decay of plankton held up at this level. The deeper layers show a uniformly high nitrate concentration. At station 21 the upper twenty metres were in the month of October supersaturated with oxygen and practically depleted of nitrate. Immediately below the discontinuity layer nitrite reached its maximum. Approaching Cape Guardafui the stability is comparatively low and there is distinct evidence of turbulence. Unfortunately no quantitative plankton observations were made, but Gilson suggests that the low transparency of the water in the months of September and October indicates that the subsurface layers must have been rich in plankton. The low transparency cannot be attributed to material washed in from the land, as there are no rivers in this area.

When the expedition revisited the area in May warming of the sun had pushed the thermocline deeper, and plankton penetrating to the deeper layers through the less sharp discontinuity had carried the depletion of nitrate almost to the limit set by illumination.

In addition active plankton production was in progress as the supply of nutrients was no longer cut off by the steep and shallow thermocline.

The oceanographical observations suggest, therefore, a rich plankton-producing area, probably from October to May, and the organic carbon content of the bottom sediments confirms this conclusion.

(β) *The Arabian Coast.*

Upwelling occurs along this coast during the S.W. monsoon and consequently supplies of nutrients are brought to the surface. The expedition visited this area in October, and Gilson suggests that the oxygen, nitrite and transparency figures indicate that a period of considerable plankton production was coming to an end. The two samples investigated from this area, M7645 and M7644 (British Museum collections), contain respectively 3·09 and 1·62% of organic carbon on a H_2O–free basis. There is therefore a relation between the carbon content of the sediments and the plankton production.

(γ) *The Gulf of Oman.*

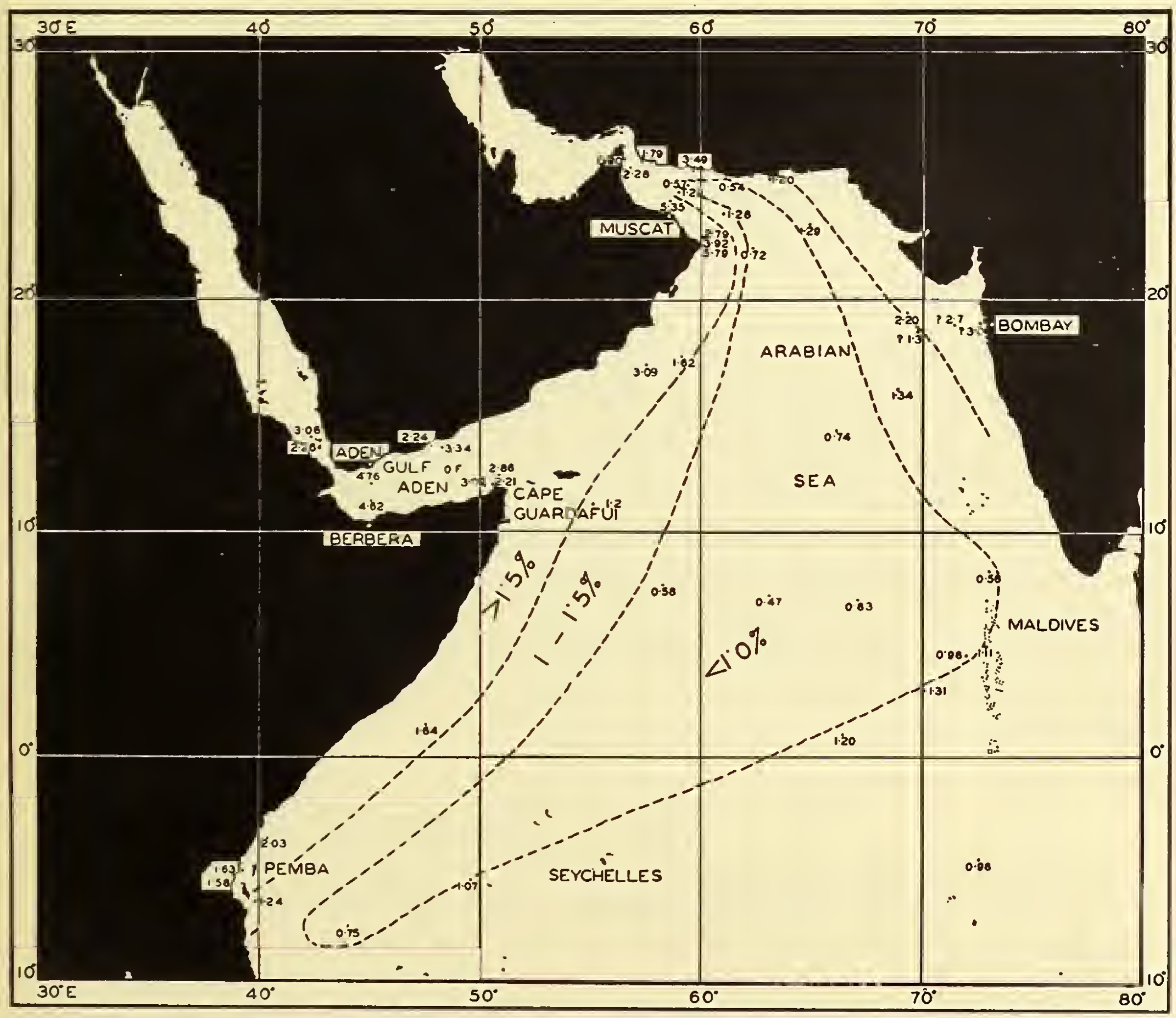
This area is characterized by low organic carbon in the centre, apparently connecting with the central area of the Arabian Sea. High organic carbon occurs along the coastal regions apart from one shallow water station 73. Unfortunately the oceanographical observations were taken in the month of November, so any outburst of plankton at the break-up of the S.W. monsoon would have been long past. It is interesting to note, however, that there is at about a depth of 150 metres on the Arabian side a tongue of low salinity water but rich in nitrate coming out of the Persian Gulf. The upper 30- to 40-metre layer is completely depleted of nutrient salts and consequently the oxygen figures are low. In a longitudinal section of the Gulf of Oman Gilson considers that there is little turbulence, and although the stability is not very high it is sufficient to prevent enrichment from the productive zone below. A correlation exists, therefore, between the sediments, moderately poor in organic carbon, from the central area and oceanographical considerations. The high carbon content of the coastal sediments would suggest however that at some period of the year there must be a considerable renewal of nutrients from below.

(δ) *The Arabian Sea.*

At station 85 2·20% organic carbon occurs, whilst Trask (1932*c*) has reported that the British Museum samples (M7631, M7624 and M7617) collected off Bombay contain 0·09, 0·19 and 0·21% nitrogen, corresponding to more than 1·5% of organic carbon. Proceeding into mid-oceanic waters only 0·74% of organic carbon occurs at station 93, whilst approaching the African coast organic carbon again increases, for a British Museum sample (M4302) S.E. of Socotra contains 0·08% of nitrogen (Trask, 1932*c*), corresponding to approximately 1·5% organic carbon. Along the African coast 1·64% organic carbon occurs at station 101, whilst at station 117, 2·03%. The sediments investigated from the Pemba Channel contain more than 1·5% organic carbon.

Matthews (1926) has demonstrated that during the S.W. monsoon season the northerly current along the African coast tends to move in a more easterly direction under the influence of the wind, and upwelling of deeper water results along the coast, and Gilson

states that at stations 100 and 101 there were still relics of this movement. The African coast is a rich plankton-producing area, and corresponding with this the sediments are rich in organic carbon. From Bombay as far as station 100, when the expedition visited this area in December to January, the surface layer was almost completely depleted of nutrient salts, and the area is probably a poor one in plankton production. This hypothesis agrees with the low carbon found at station 93, but the authors consider that the



Text-fig. 1.—Distribution of organic carbon in the Arabian Sea.

increasing amounts of organic carbon found in the neighbourhood of Bombay would indicate at some period of the year an appreciable plankton production.

Along the most southerly section taken by the expedition low organic carbon occurs at station 127, 1% at station 128, 1·2% at station 132, and 1·3% at station 134. The present results would therefore suggest that in the southern portion of the Arabian Sea some of the sediments contain more than 1% organic carbon.

When the expedition visited this area in February to March the surface layer had a comparatively low stability, and mixing by the wind was very marked in the west, but as

the compensation level lay below the limit of such mixing it could cause no renewal in the supply of nutrients. In this connection it is interesting to recall the low organic carbon at station 127. Gilson considers that in the truly oceanic stations an outburst of plankton occurs at the end of the S.W. monsoon season, and that upwelling occurs on the lee side of the Seychelles Bank. The increased carbon content in the sediments may be correlated with these facts. At station 134 the low salinity surface water indicates an influx of water brought by the N.E. monsoon from the Bay of Bengal, Andaman Sea and the Malay region, and it has been suggested by Gilson that since enormous quantities of nitrate are brought down into the Bay of Bengal by the Ganges, this water may have a high nitrate content.

In the central section low amounts of organic carbon occur (ranging from 0·83% at station 166 to 0·47% at station 167), and this suggests that no very extensive plankton production takes place in this area. When the expedition visited this area in April, 1934, the transparency was high, but the utilization of the nutrients in the upper layer is incomplete, which may be due to the supply of nitrates being in excess of that of plankton production.

At station 169 on the Carlsberg Ridge Gilson reports abundant plankton and correlates this with the upward movement of the deep water. Unfortunately no bottom sample was collected, so it is impossible to say whether the rich plankton at this station affects the carbon content of the bottom sediments.

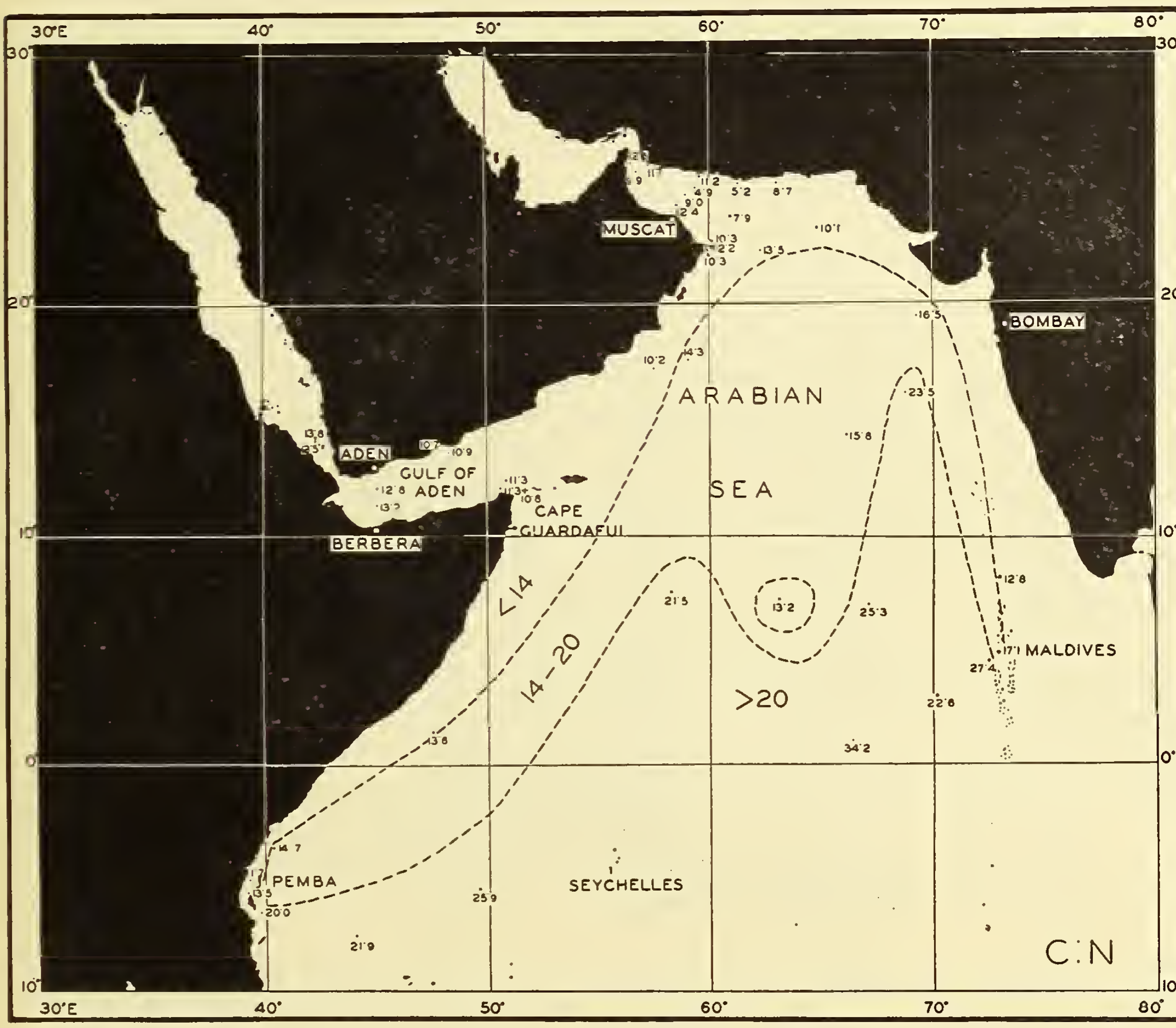
From the above results it may be said that in the Arabian Sea a connection exists between the productivity of the ocean and the organic carbon content of the sediments. The existence of such a relation should be of considerable use to those interested in the productivity of the oceans, and it would seem advisable for expeditions investigating the distribution of oceanic plankton to determine the organic carbon contents of marine deposits. The authors consider that interesting and corroborative evidence could be obtained by this method.

(*b*) The C : N Ratio in Surface Samples.

In the investigated sediments the C : N ratio varies between 4·9 and 34·2. Text-fig. 2, showing the distribution of the C : N ratio suggests, however, a tendency for regional constancy. In the Red Sea sediments from two neighbouring stations (207 and 206) have ratios 13·5 and 13·8 respectively, whilst the average of seven from the Gulf of Aden is 11·5, the ratio varying between 10·6 and 13·2. Along the Arabian Coast two samples have ratios 10·2 and 14·3 respectively, and in the Gulf of Oman the ratio varied between 4·9 and 13·5, the average for 15 different stations being 10·0. In the neighbourhood of the African coast, at station 101, C : N is 13·6 and 14·7 at station 117, whilst in the Pemba Channel two stations (114 and 106) have ratios 11·7 and 13·5, the average for the African coast being 13·4. At station 119, S.E. of Zanzibar, the C : N ratio is 20·0. This high value was rather unexpected, owing to its proximity to Africa, but similar values occur in the southern portion of the Arabian Sea. In eight selected oceanic stations values varied between 21·9 and 34·2, the average being 25·2. These high ratios are interesting, but it must be pointed out that this is not characteristic of all oceanic sediments, for stations 167 and 93 from the middle of the Arabian Sea have C : N ratios 13·2 and 15·8 respectively. Reviewing the available results, it may be concluded

that Arabian Sea coastal sediments have generally a C : N ratio smaller than 15, apart from station 119.

No obvious relation exists between the C : N ratio, depth or $CaCO_3$ content, nor is this ratio connected with the oxygen content of the bottom water. It might, however, be suggested that the lower ratios are due to the incoming of land organic debris, but this seems unlikely because low values occur in the middle of the Arabian Sea, and in addition



Text-fig. 2.—C : N ratio in sediments from the Arabian Sea.

the absence of large rivers capable of transporting appreciable quantities of land humus opposes such a hypothesis. Finally the lower ratios are not always maintained in the deeper portions of the cores. For example at station 101 the C : N ratio is 13·6 at the top and 19·7 in a deeper portion of the core, and again at station 62 the value at the top is 10·1 and 17·6 below. Conversely at station 132 the C : N ratio at the top is 34·2, whilst in a deeper portion it is 17·3.

Mention has previously been made of the variability of the C : N ratio in the Murray Samples, and of the errors introduced by calculating organic matter from the nitrogen

content. The basic idea underlying a relatively constant C : N ratio in marine sediments is organic matter of uniform composition, irrespective of locality and environmental conditions. Waksman (1929) has suggested that decomposition processes bring about an accumulation of resistant substances of plant origin and of nitrogenous substances of microbiological origin. As decomposition advances, the ratio of C : N in the product tends to become fairly constant, its value ranging from 8 to 12, the mean being 10.

The average C : N ratio for 108 sediments investigated by Trask (1932*d*) is 8·4, but in the Arabian Sea the average for 44 surface samples is 14·4, with variations from 4·9 to 34·2. The reason for the difference between these two averages is probably due to the sediments investigated by Trask coming from near shore environments. Similarly, Waksman's (1933*b*) conclusion that the C : N ratio of marine sediments is more or less constant is based on an inadequate study of deep-sea deposits. Gripenberg (1934*e*) found that the mean for Baltic sediments was 10·0, a ratio appreciably higher than that found by Trask. In the Baltic regional differences are found in the C : N ratio, the highest ratios occurring in the Bay of Bothnia. These variations are accounted for by the influence of land humus on organic sedimentation, the C : N ratio of humus from peat bogs being high. As plankton and animal life is poor in the Bay of Bothnia, the greatest effect is noticed here in spite of the fact of the moderately low addition of land humus.

A survey of the available results indicates that the idea of a constant C : N ratio for marine deposits originates through a study of deposits collected near the coast, and a further unwarranted application of this result to the uninvestigated oceanic regions. Our investigations, as previously mentioned, suggest that in the Arabian Sea coastal sediments have generally a ratio below 15, and that sediments farther out have a higher ratio, though exceptions, such as station 167, can be found to such a general rule.

The authors, although they cannot put forward a complete explanation for the reason of these apparent regional variations, suggest that it is largely due to some environmental conditions. That marine organic matter is not absolutely resistant to further decomposition by bacteria has been shown, as previously mentioned, by Waksman (1933*c*), who treated mud under purely artificial conditions and found a reduction in the C : N ratio. If a change in the C : N ratio can be brought about in laboratory experiments, it would seem unlikely that marine organic matter collecting on the bottom would be entirely uninfluenced by the surrounding conditions.

(*c*) Variations of Organic Carbon and Nitrogen with Depth in Sediment.

In order to determine whether there is a marked difference in the organic content of marine deposits at different ages, estimations were done on deeper portions of 16 cores. For convenience the results are collected in Table V. In seven cores the organic carbon (calculated on a H_2O– and NaCl free basis) decreases in the lower investigated portions, whilst in four cores organic carbon at first decreases and then increases. Three cores show an increase and then a decrease, whilst in the Red Clay core (station 166) a decrease, within the limits of experimental error occurs.

Nitrogen (recalculated without H_2O– and NaCl), apart from five cases, behaves sympathetically with organic carbon, but the C : N ratio does not, in general, remain constant in the lower portions of the cores. Organic carbon recalculated on a $CaCO_3$,

Table V.

Station No.	Organic carbon on a H_2O– and NaCl free basis.	Organic carbon on a $CaCO_3$, H_2O– and NaCl free basis.	Nitrogen on a H_2O– and NaCl free basis.	Nitrogen on a $CaCO_3$, H_2O– and NaCl free basis.
33 Top	3·34	6·80	0·306	0·622
33 (37½ cm.)	2·26	5·22	0·168	0·389
66 Top	5·35	8·26	0·432	0·667
66 (43 cm.)	4·62	6·99	0·306	0·463
20 Top	4·76	10·55	0·372	0·824
20 (41¼ cm.)	2·51	6·79	0·166	0·449
62 Top	1·29	1·79	0·128	0·178
62 (20¾ cm.)	0·84	1·41	0·048	0·080
26 Top	2·86	5·90	0·252	0·521
26 (30½ cm.)	1·69	5·06	0·126	0·379
26 (54½ cm.)	1·60	5·82	0·113	0·412
128 Top	1·07	3·98	0·041	0·154
128 (48¼ cm.)	0·82	4·87	0·023	0·137
128 (99 cm.)	0·63	2·51	0·024	0·098
134 Top	1·31	3·32	0·058	0·147
134 (107½ cm.)	0·81	1·85	0·037	0·084
134 (118 cm.)	0·67	1·51	0·037	0·084
21 Top	4·62	11·04	0·351	0·838
21 (38¾ cm.)	5·25	8·71	0·452	0·751
106 Top	1·58	4·76	0·117	0·352
106 (32¼ cm.)	1·65	4·95	0·121	0·365
106 (54½ cm.)	1·48	4·65	0·108	0·337
119 Top	1·24	3·13	0·062	0·157
119 (31¼ cm.)	1·89	2·99	0·123	0·195
119 (66¾ cm.)	1·14	2·83	0·059	0·145
135 Top	0·98	7·40	0·036	0·271
135 (62¾ cm.)	1·10	3·49	0·057	0·181
135 (114¾ cm.)	0·90	4·26	0·038	0·178
132 Top	1·20	5·32	0·035	0·155
132 (48¾ cm.)	0·75	2·60	0·043	0·150
132 (114¼ cm.)	0·81	3·04	0·036	0·134
101 Top	1·64	2·73	0·120	0·200
101 (32¼ cm.)	1·14	2·82	0·063	0·155
101 (88¼ cm.)	1·64	4·55	0·083	0·231
93 Top	0·74	2·00	0·047	0·127
93 (50 cm.)	0·59	0·93	0·040	0·063
93 (83¾ cm.)	0·72	0·97	0·056	0·075
167 Top	0·47	1·74	0·036	0·132
167 (48¼ cm.)	0·32	0·98	0·027	0·082
167 (108¾ cm.)	0·52	1·35	0·033	0·087
166 Top	0·83	0·85	0·033	0·034
166 (22¼ cm.)	0·70	0·72	0·040	0·041
166 (50¼ cm.)	0·72	0·74	0·045	0·046
166 (76¼ cm.)	0·53	0·54	0·050	0·051

H_2O– and NaCl free basis behaves in thirty-seven cases sympathetically with the organic carbon.

Comparing these results with the "Meteor" cores (Correns, 1937*a*) considerable agreement is noted, as Correns found that the organic carbon content sometimes decreases with depth, increases, or oscillates. Waksman (1933*b*) considers that there is generally a slow and gradual diminution in the amount of organic matter with depth, though in some cases the reverse holds, whilst Gripenberg (1934*f*) found that, to the depths reached by the sampler, late glacial clays had a uniform organic content, but post-glacial sediments decrease in organic matter in sediments from the Bay of Bothnia, but increase elsewhere. The content of organic matter at any depth in a core is a function of several factors, and does not solely depend on the productivity of the area when the sediment was deposited. It appears, however, that two factors may influence, in opposite directions, the organic content: the first being the decrease with depth caused by time of burial and biological considerations, the second being an increase with depth due to a decrease in the rate of sedimentation.

The rate of sedimentation is, in general, governed by two factors: firstly the amount of inorganic detritus (clay and other mineral particles) reaching the bottom, and secondly the amount of carbonate material, largely in the form of shells, arriving at the sea bottom. In many marine samples carbonate is greatly in excess of the clay and mineral components, and consequently a more accurate knowledge of the productivity may be obtained in such samples by calculating the organic carbon and nitrogen on a carbonate-free basis. The results of this recalculation are shown in the third and fifth columns of Table V.

(*d*) Variations of the C : N Ratio with Depth in Sediment.

The variations of the C : N ratio with depth and its relation to CO_2 content (recalculated without H_2O– and NaCl) are recorded in Table VI. From this table it is seen that an increase of the C : N ratio is accompanied by an increased CO_2 content, apart from the lower portion of station 66, and that a decrease of the C : N ratio is associated with a decreased CO_2 content in all cases except in the lowest portion of station 166. It is questionable whether the lower portion of the core at station 66 is really an exception, because the recalculated CO_2 figure is doubtful. (H_2O– was done at a later time and not on the same material.) In this connection it is significant to note that $CaCO_3$ uncorrected for H_2O– and NaCl has the following values: 31·11% in the upper portion and 31·34% in the lower portion.

Similarly the lowest portion of station 166 cannot rigorously be held as an exception; as the amounts of carbon and nitrogen are low, the limits of error could easily account for the discrepancy.

The top, middle and lower portions of the core from station 106 have practically the same CO_2 content, and corresponding with this the C : N ratio shows small variations. In some cores the C : N ratio oscillates, the middle portion having a lower or higher ratio than the top and bottom portions. In accordance with this behaviour the CO_2 content varies sympathetically, the only exception being the lowest portion of Station 167, and as the nitrogen is low, this can easily be accounted for by experimental error in the carbon or nitrogen determinations.

TABLE VI.

	Station No.	C : N.	CO_2.
Increase	62 Top	10·1	12·27
	62 (20¾ cm.)	18·7	17·86
	33 Top	10·9	22·37
	33 (37½ cm.)	13·4	24·92
	26 Top	11·3	22·69
	26 (30½ cm.)	13·4	29·33
	26 (54½ cm.)	14·1	31·88
	66 Top	12·4	15·48
	66 (43 cm.)	15·1	14·91
	20 Top	12·8	24·12
	20 (41¼ cm.)	15·1	27·70
	101 Top	13·6	17·56
	101 (32¼ cm.)	18·1	26·17
	101 (88¼ cm.)	19·7	28·17
Decrease	21 Top	13·2	25·57
	21 (38¾ cm.)	11·6	17·50
	93 Top	15·8	27·75
	93 (50 cm.)	14·6	15·95
	93 (83¾ cm.)	12·9	11·39
	134 Top	22·6	26·68
	134 (107½ cm.)	22·1	24·84
	134 (118 cm.)	18·0	24·41
	166 Top	25·3	1·14
	166 (22¼ cm.)	17·6	0·88
	166 (50¼ cm.)	16·0	0·71
	166 (76¼ cm.)	10·7	1·02
Approximately	106 Top	13·5	29·36
the same	106 (32¼ cm.)	13·6	29·34
	106 (54½ cm.)	13·8	29·93
Oscillate	167 Top	13·2	32·10
	167 (48¼ cm.)	11·9	29·43
	167 (108¾ cm.)	15·6	26·96
	119 Top	20·0	26·58
	119 (31¼ cm.)	15·4	16·19
	119 (66¾ cm.)	19·4	26·19
	128 Top	25·9	32·10
	128 (48¼ cm.)	35·5	36·60
	128 (99 cm.)	25·7	32·98
	135 Top	27·4	38·17
	135 (62¾ cm.)	19·3	30·13
	135 (114¾ cm.)	23·9	34·71
	132 Top	34·2	34·05
	132 (48¾ cm.)	17·3	31·34
	132 (88¼ cm.)	22·6	32·27

From these results it may tentatively be concluded that in the lower portions of the cores a sympathetic relation exists between the CO_2 content and the C : N ratio. The authors do not consider this relation as fortuitous, as estimations have been carried out at sixteen stations, nor would it seem likely that it is due to the limits of error in the organic carbon and nitrogen determinations. The possible experimental errors could alter appreciably the C : N ratio, especially when these substances occur in small amounts, but even with the maximum experimental errors occurring in the most favourable way no alteration of this relation occurs at five stations, whilst in general at the other stations the relation holds for two portions of the core and not for the third. It would seem unlikely that experimental errors acted suitably so as to give an artificial relation, especially as these possible exceptions only occur in samples poor in organic matter. Although there is, at present, sufficient evidence to suggest this relation, more determinations would have been desirable. The limitations of time, however, prevented more cores from being examined, and unfortunately no information is available in the literature. It would be unreasonable to expect this relation to hold for all oceanic deposits, but it should apply to those deposits in which there is a connection between the carbonate content and the physical and chemical properties of the bottom water.

In order to attempt a possible explanation it is necessary to point out the conditions which govern the solubility of $CaCO_3$ in sea-water. Johnston and Williamson (1916) demonstrated that the precipitation and solution of $CaCO_3$ in sea-water is governed by the law of mass action, $[Ca^{++}] \times [CO''_3] = K'_{CaCO_3}$, in which the brackets represent molar concentration, and K'_{CaCO_3} is the stochiometric solubility product in the presence of solid $CaCO_3$. From this equation it follows that under any conditions the solubility of $CaCO_3$ is controlled by the concentrations of calcium and carbonate ions and the value of the constant K'_{CaCO_3}. It is well known that salinity, temperature, hydrostatic pressure, CO_2 content and pH affect these factors, and it has been the task of several oceanographers to determine how these several factors affect the solubility.

The total concentration of calcium can be measured directly (Kirk, 1933), or its variations can be determined from the variations in the titratable base (Wattenberg, 1933), but the concentration of carbonate ions cannot be determined directly. It may, however, be calculated from the first and second dissociation constants of carbonic acid in sea-water, provided the pH is known. The first dissociation constant, at a salinity of $34°/_{oo}$ and temperature of 20°, has a value of 10^{-6} (Buch, 1932), but the value of the second dissociation constant (Buch, 1930; Moberg, 1934) is more questionable. Further, as boric acid is present to the extent of about 18% of the titratable base, a correction for boron must be applied in order to determine the amount of the base which is balanced against carbonic acid. The first and second dissociation constants of $CaCO_3$ in sea-water vary with the salinity and temperature, but relations have been established between these factors. Finally, the effect of hydrostatic pressure on the dissociation constants of carbonic acid is unknown. Revelle (1934) has given a most useful table showing the comparative effects of changes in salinity, temperature and carbon dioxide content on the components of the system controlling the solubility of calcium carbonate. At saturation

$$\frac{[Ca^{++}] \times [CO''_3]}{K'_{CaCO_3}} = 1,$$

and in under-saturation solution this quotient is less than 1. According to Revelle at a

depth of 1000 metres (salinity 36°/₀₀, temperature 5° C.) a change in the carbon dioxide content from 2·35 millimoles per litre to 2·40 per litre reduces the saturation quotient by −23%. He concludes that the most important factor controlling the solubility of $CaCO_3$ in sea-water is the CO_2 content, and the order of importance of the other physical constants is temperature, salinity and hydrostatic pressure.

In attempting to explain the possibility of the C : N ratio influencing the solubility of $CaCO_3$, it is first necessary to point out that the CO_2 content of sea-water is largely controlled by biological activity. If equilibrium conditions exist between the bottom water and sediment, a reduction of this ratio would increase the CO_2 content of the bottom water, and consequently the amount of carbonate in the sediment would decrease. With changing conditions it is possible, at a subsequent time, for the regeneration of organic carbon with reference to nitrogen to decrease (*i. e.* the C : N ratio increases). The CO_2 content of the bottom water would decrease and consequently the sediment would have an increased carbonate content. It is, therefore, possible to explain in the cores the apparent connection between the C : N ratio and carbonate content, but it is difficult to put forward any suggestion about the factors which favour the regeneration of organic carbon, as very little is known about the viability of bacteria in oceanic sediments and the conditions favouring the production of nitrifying or CO_2-producing bacteria. It would seem, therefore, impossible to suggest the conditions favourable to the development of certain specific bacteria until bacteriologists have made more detailed investigations about the bacteriological content of marine deposits.

Sediments with a comparable carbonate content are not always accompanied by the same C : N ratio, and in addition the rate of increase of the C : N ratio is not always the same as that of the carbonate content. These facts do not oppose the above-mentioned explanation, as the solubility of $CaCO_3$ depends not only on the CO_2 content, but also on temperature, salinity and hydrostatic pressure. In addition the rate of renewal of the bottom water must affect its CO_2 content, and the rate of accumulation of the non-carbonate components may influence the carbonate content of the sediment. It would, therefore, be unreasonable to expect all stations with the same C : N ratio to have the same carbonate content.

IX. SUMMARY AND CONCLUSIONS.

The amount of organic carbon and nitrogen has been determined on bottom sediments from 44 Arabian Sea Stations, and estimations have been made on the lower portions of 16 cores. In the Arabian Sea there is a large central area extending into the Gulf of Oman where the organic carbon content of the sediments is less than 1%. Surrounding this is a belt containing 1–1·5%, and then a coastal area with greater content. The distribution of organic carbon is in general agreement with the productivity of the area determined from chemical studies and plankton hauls.

The C : N ratio in surface samples varies between 4·9 and 34·2, though there is a tendency for a regional constancy of this ratio ; the average ratio for surface samples is 14·4. Previously it has been suggested by some investigators that, as a routine procedure, the estimations of organic matter can be most satisfactorily obtained from nitrogen, but the authors consider that this is likely to lead to very inaccurate results because of the variability of the C : N ratio.

In the lower portions of the investigated cores organic carbon and nitrogen may decrease, increase, or oscillate. The variations of the C : N ratio in the lower portions agree, in general, with the variations of the $CaCO_3$ content, and a provisional explanation for this is suggested. It is, in conclusion, to be hoped that future expeditions studying the productivity of the oceans will not ignore the information which may be obtained from the sediments, and will collect bottom samples with all possible oceanographical data. By this means more useful results will be obtained, which will be helpful in the interpretation of other problems.

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